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Dynamic Response of X-37 Hot Structure Control Surfaces Exposed to Controlled Reverberant Acoustic Excitation

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January 2005

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Abstract

This document represents a compilation of three informal reports from reverberant acoustic tests performed on X-37 hot structure control surfaces in the NASA Langley Research Center Structural Acoustics Loads and Transmission (SALT) facility. The first test was performed on a carbon-silicone carbide flaperon subcomponent on February 24, 2004. The second test was performed on a carbon-carbon ruddervator subcomponent on May 27, 2004. The third test was performed on a carbon-carbon flaperon subcomponent on June 30, 2004.

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1. C/SiC Flaperon

1.1 Introduction

The Boeing X-37 vehicle incorporates a hot structure "Flaperon" control surface that will be subjected to vibratory and acoustic loads from the lift-off mission phase of flight. A subcomponent design for the carbon-silicone carbide (C/SiC) Flaperon was developed and manufactured. This subcomponent incorporates the major features of the full scale control surface, including the inboard spindle, a torque tube with a 180^{o} cutout containing an outboard hinge pin assembly, bottom face sheets, and a continuous top face sheet which serves as an access panel for assembly of the Flaperon itself. The goal of the Flaperon subcomponent vibro-acoustics tests is to simulate the dynamic response of the C/SiC Flaperon subcomponent when subjected to excitation loads corresponding to the lift-off environment for this hot structure control surface. Measured responses will be compared to predicted strains and accelerations to determine the validity of the mathematical model for this C/SiC subcomponent test article. This report covers the vibro-acoustic testing in the reverberation room of the Structural Acoustics Loads and Transmission (SALT) facility (Reference 1-1) at NASA Langley Research Center.

1.2 Acoustic Test Objective

The objective of the vibro-acoustic test is to measure the dynamic response of the C/SiC Flaperon subcomponent when subjected to the acoustic loads corresponding to an envelope of the Atlas V and Delta IV launch environments. The measured responses (acceleration and strain) will be used to assess the construction techniques and mathematical model using a stochastic acoustic input that replicates the launch environment of the X-37 vehicle. This document describes the test article, the facility configuration, test setup, instrumentation, acoustic test loads spectra, test sequence, test results, and the data reporting of the C/SiC Flaperon subcomponent.

1.3 Test Article

The C/SiC Flaperon subcomponent test article consists of carbon-silicone carbide (C/SiC) composite materials fabricated by GE Power Systems Composites (GE PSC). The architecture of all the elements of the Flaperon, including the torque tube, ribs, gussets, and face sheets, is specified as quasi-isotropic layups $(0/45/90/-45)_{nS}$. A picture of the test article with the access panel removed is shown in Figure 1-1.

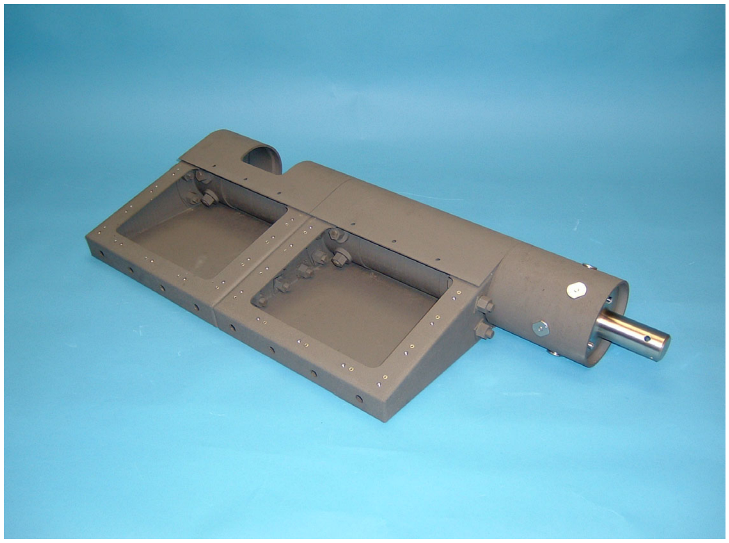

Figure 1-1: Picture of the test article with access panel removed.

The test article was mounted on an aluminum interface plate as shown in the sketch of Figure 1-2. A support structure (Figure 1-3) was mounted to the floor of the reverberation chamber and filled with sand. The support structure is used to elevate the test article for better exposure of the acoustic environment. The test article and aluminum interface plate were mounted to the top of the support structure. The test procedures document in Reference 1-2 provides the details on the designs, the drawings, and test setup installation procedures of the test article and support structure.

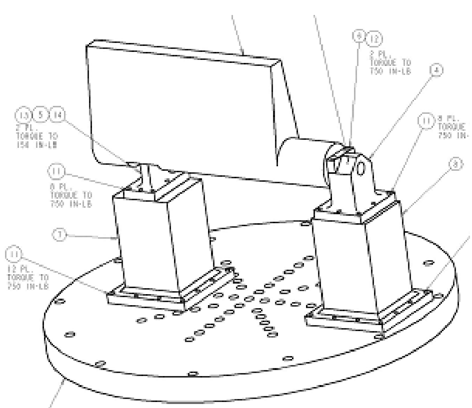

Figure 1-2: Test article & aluminum interface plate.

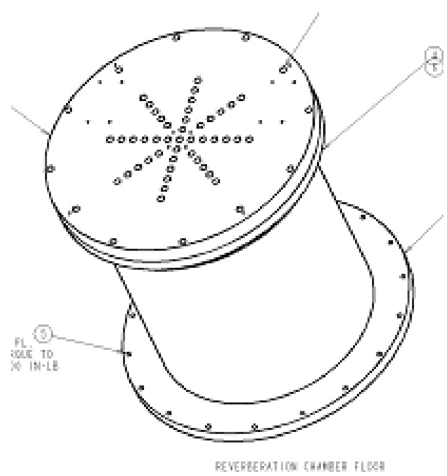

Figure 1-3: Test article support structure.

1.4 Test Article Instrumentation

The instrumentation sensor suite consists of accelerometers and foil-strain gage sensors (Figure 1-4). The locations of these sensors are prescribed in the test procedures document (Reference 1-2). Small 0.02 oz, 10 mV/g accelerometers were used for this test. One version is a PCB 352B22 and Model 352C22; the other is an Endevco Model 2250A-10. The mounting block weight is typically 0.08 oz. There are a total of 48 accelerometers installed on the test article in tri-axial (8 positions), bi-axial (6 positions), and uni-axial (6 position) configurations (Figure 1-5).

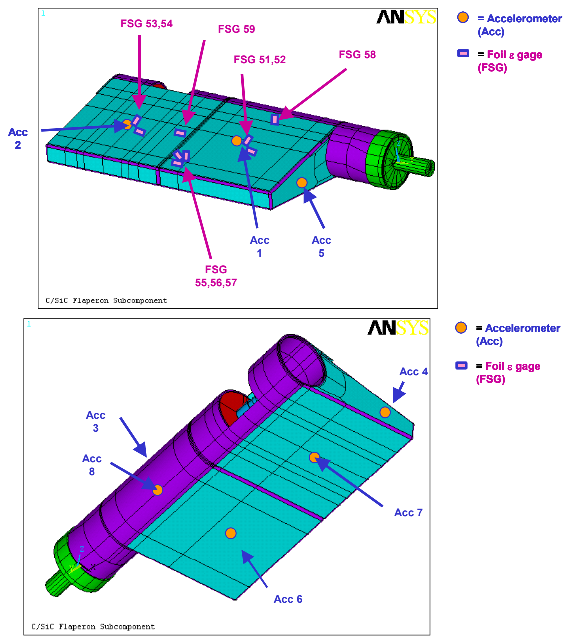

Figure 1-4: Location of accelerometers and foil strain gages.

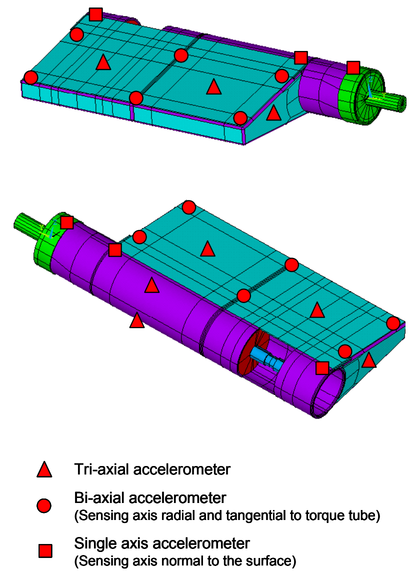

Figure 1-5: Accelerometer configurations.

The bi-axial and tri-axial configurations were achieved using an accelerometer-mounting block. The X, Y, and Z coordinate axes origin and orientations for the accelerometers are shown in Figure 1-6. A total of 9 foil strain gages (1 rosette and 6 singles) were fitted on the test article. Figure 1-7 shows the instrumented test article installed on its support in the reverberation chamber.

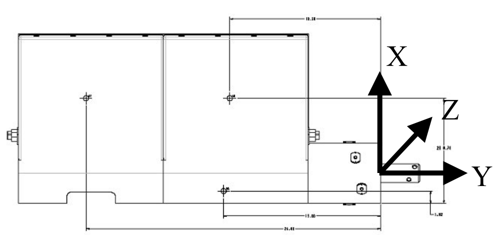

Figure 1-6: Coordinate axes origin and orientations for the accelerometers.

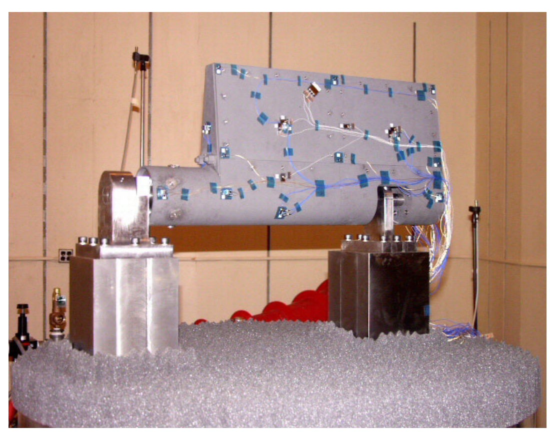

Figure 1-7: Instrumented test article in the reverberation chamber.

Table 1-1 lists the accelerometer locations, orientations, serial numbers, and coordinates for the dynamic response tests in the reverberation chamber.

Table 1-1: Accelerometer locations and orientations.

Location	Orientation	Accelerometer	Serial Number	Coordinate [in]		
				x	y	z
1	x	1	11710	6.125	-12.500	1.674
1	-y	2	11711			
1	z	3	11714			
2	x	4	11713	6.125	-24.500	1.674
2	-y	5	18399			
2	z	6	18402			
3	x	7	18405	-1.500	-12.000	2.000
3	y	8	18406			
3	z	9	18407			
4	x	10	18408	6.000	-30.000	0.000
4	-y	11	18410			
4	z	12	18411			
5	x	13	18412	6.000	-6.000	0.000
5	y	14	18413			
5	z	15	18415			
6	x	16	18416	6.250	-12.550	-1.657
6	-y	17	18418			
6	-z	18	18419			
7	x	19	18420	6.250	-24.500	-1.657
7	-y	20	18421			
7	-z	21	4159			
8	x	22	ET79	-1.500	-13.000	-2.000
8	-y	23	AF818			
8	-z	24	1114			
25	z	25	11077	3.438	-29.750	2.037
26	z	26	12910	3.438	-18.000	2.037
27	z	27	14121	3.438	-6.250	2.037
28	z	28	14160	11.250	-6.250	0.983
29	z	29	14180	11.475	-18.000	0.953
30	z	30	14183	11.475	-29.750	0.953
31	-z	31	14205	11.100	-29.600	-1.003
32	-z	32	14206	11.100	-17.500	-1.003
33	-z	33	14208	11.100	-6.400	-1.003
34	-z	34	14363	3.400	-6.400	-2.042
35	-z	35	14364	3.400	-17.500	-2.042
36	-z	36	14414	3.400	-29.600	-2.042
37	-z	37	14415	0.100	-29.500	-2.487
37	x	38	13449			
38	x	42	AF806	0.100	-6.450	-2.870
38	-z	43	DD43			
39	x	44	ET-40	0.100	-0.700	-2.487
39	-z	45	11113			
40	x	46	11120	0.100	-29.500	2.487
40	z	47	11078			
41	z	48	11083	0.100	-6.450	2.487
41	-x	49	11096			
42	x	50	12858	0.100	-0.700	2.487
42	z	39	11111			

Strain gage locations and orientations are provided in Reference 1-3.

1.5 Acoustic Test Facility

The 9800 ft^3 SALT facility reverberation chamber (Reference 1-1) is structurally isolated from the rest of the building and measures approximately 14.8 ft by 21.2 ft by 31.2 ft. Figure 1-8 shows the reverberation chamber with the instrumented test article mounted on the sand-filled pedestal support. Rigid close-out panels were installed in the transmission loss window (separating the reverberation room from the anechoic chamber) on the left and the flow duct on the right.

Figure 1-8: Test article mounted on the pedestal support structure in the reverberation chamber.

The chamber walls and ceiling of the reverberation chamber are splayed to diminish the effects of standing waves between opposite surfaces and are separated by a 30-inch air gap from the surrounding 18-inch thick concrete building walls. The total surface area of the walls, floor, and ceiling is approximately 3120 ft^2. One-third octave band ambient noise levels were measured previously (Reference 1-1) in the reverberation chamber and are listed in Table 1-2. The minimum frequency for a diffuse sound field in the reverberation room was calculated to be 83.2 Hz yielding the 100 Hz and higher one-third octave bands (Reference 1-1). T(20) reverberation times, the estimated times required for a 60 dB sound pressure level (SPL) decrease based on the SPL decays between –5 dB and –25 dB, are also listed in Table 1-2.

Table 1-2: Background noise levels and reverberation times in the reverberation room.

1/3 Octave Band Center Frequency [Hz]	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000
Background Noise Level [dB]	34.4	32.1	43.2	27.6	26.9	28.9	22.6	20.7	12.4	12.6	12.3	10.2	9.5	7.6	7
Reverberation Time (T20) [s]	23.3	15.0	13.5	14.2	15.8	15.3	14.9	13.7	12.4	10.8	9.4	8.4	7.0	5.8	5.1

1.6 Test Equipment and Instrumentation

Excitation in the reverberation chamber was provided by three types of acoustic drivers to cover the one-third octave band frequency range from 40 Hz through 2000 Hz. The low frequencies were generated by two subwoofers, the mid-frequencies by a dual-driver pneumatic horn, and the high frequencies were generated by compact compression drivers. Figure 1-9 shows one of the subwoofers and a compression driver in the reverberation chamber. The pneumatic horn in the reverberation chamber is depicted in Figure 1-10.

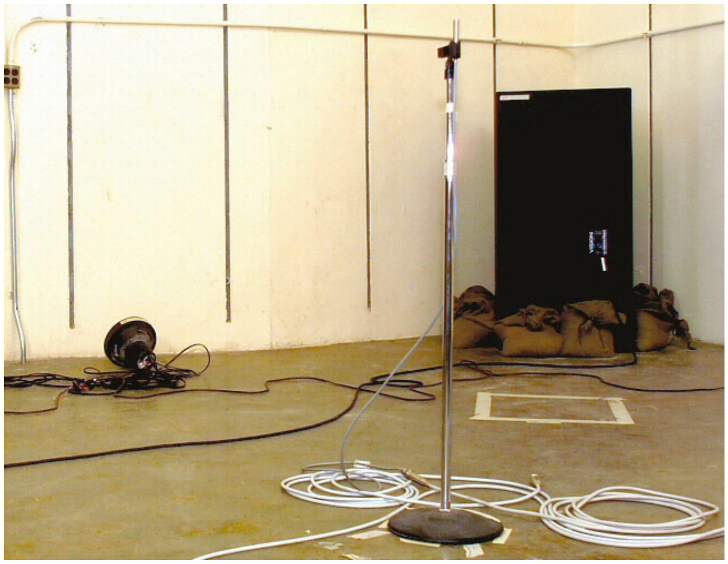

Figure 1-9: The low-frequency subwoofer (right) and high-frequency compression driver (left on the floor).

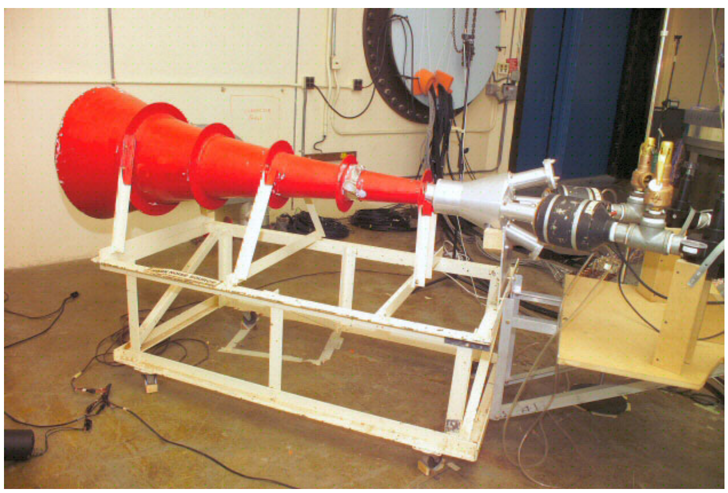

Figure 1-10: The pneumatic horn outfitted with two mid-frequency acoustic drivers.

An acoustic control system used the averaged measured signals of six control microphones to have the three types of acoustic drivers generate the required acoustic spectrum shape inside the reverberation chamber. The control system will be described in detail in Section 1.8. Descriptions of the acoustic equipment, instrumentation, and settings used during the tests, including model, serial number, and calibration information are listed in Table 1-3 and Table 1-4.

Table 1-3: Acoustic equipment and instrumentation descriptions for the X-37 C/SiC Flaperon testing.

A1 **Amplifier** Crown Micro-Tech 600 A019775 Bridge Mono 655 Watts at 8 Ohms Input: XLR 1 Output: +1, +2 Gain: Full	**A2** **Amplifier** Crown Micro-Tech 600 A019774 Bridge Mono 655 Watts at 8 Ohms Input: XLR 1 Output: +1, +2 Gain: Full	**A3 and A4** **Amplifier** Crown CE4000 Bridge Mono 2800 Watts at 4 Ohms Input: XLR 1 Output: +1, +2 Sensitivity: 1.4 V Ch1: Flat low-pass Ch2: N/A Gain: Full
A5 **Amplifier** Crown Micro-Tech 600 A019773 Bridge Mono 655 Watts at 8 Ohms Input: XLR 1 Output: +1, +2 Gain: Full	**A6** **Amplifier** Crown Micro-Tech 600 A019773 Bridge Mono 655 Watts at 8 Ohms Input: XLR 1 Output: +1, +2 Gain: Full	**F1** **Filter** Krohn-Hite 3342R A033067 ECN 429787 Freq 1 Hz High Pass Line Opr Gain: 20 dB Left channel 1 (Front) Right channel not used
Sc1 **8-Channel Multiplexer** Bruel & Kjaer Model 2811 Use: Signal Conditioning ECN: 1090893 Cal due: 3/17/04	**Ec1** **Acoustic Control System** M+P International, Inc. VXI Technology VT1433B input	**Pph1** **Piston phone** Bruel & Kjaer 4228 Nominal: 124.0 dB at 250 Hz Ser: 2034885 ECN: A031171 Cal due: 5/28/04
L1 and L2 (mid) **Pneumatic Horn** Ling (2) Model: EPT94B Frequency Range: 100Hz-1000Hz	**L3 and L4 (low)** **Dual 18" Subwoofer** Cerwin Vega (2) Vis-218 Parallel Mode Input Frequency Range: 29Hz-300Hz Peak: 2800 Watts	**L5 - L10 (high)** **Compression Driver** JBL (6) Model: 2485J Frequency Range: 300Hz-6kHz Continuous: 120 Watts

Table 1-4: Microphone and preamplifier specifications.

Mic1 **Microphone** Bruel & Kjaer 4133 Ser: 1854456 ECN: A019645	**Mic2** **Microphone** Bruel & Kjaer 4133 Ser: 489484 ECN: A001311	**Mic3** **Microphone** Bruel & Kjaer 4133 Ser: 489489 ECN: A001310	**Mic4** **Microphone** Bruel & Kjaer 4133 Ser: 1854447 ECN: A019642	**Mic5** **Microphone** Bruel & Kjaer 4133 Ser: 1854444 ECN: A014311	**Mic6** **Microphone** Bruel & Kjaer 4133 Ser: 1854446 ECN: A019641
Mp1 **Microphone Preamplifier** Bruel & Kjaer 2619 Ser: 761358 ECN: A004353	**Mp2** **Microphone Preamplifier** Bruel & Kjaer 2619 Ser: 1649717 ECN: A004357	**Mp3** **Microphone Preamplifier** Bruel & Kjaer 2619 Ser: 692811 ECN: A004354	**Mp4** **Microphone Preamplifier** Bruel & Kjaer 2619 Ser: 360362 ECN: A004284	**Mp5** **Microphone Preamplifier** Bruel & Kjaer 2619 Ser: 797667 ECN: A004280	**Mp6** **Microphone Preamplifier** Bruel & Kjaer 2619 Ser: 521539 ECN: A004355

Other support equipment and instrumentation for installation of the test article and acquisition of the acceleration and strain data are summarized in Table 1-5.

Table 1-5: Test article support equipment and instrumentation.

Description	Quantity	Manufacturer	Model / Part Number
Test article structural support:			
Vibration Fixture (Aluminum Interface Plate)	1	AmTech	Drawing # 1256396
Steel Adaptor Plate	1	AmTech	Drawing # 1256402
Support Structure	1	AmTech	Drawing # 1256401
Vibration sensors:			
Measurement Accelerometer	20	PCB	352C22
Measurement Accelerometer	22	Endevco	2250A-10
Foil Strain Gages (Rosette)	1	Micro-Measurements	CEA-06-250UR-350
Foil Strain Gages (Uniaxial)	6	Micro-Measurements	CEA-06-250UW-350
Signal conditioning system:			
Chassis/Power supply	1	PCB	442A175
16-Channel Signal Conditioning	4	PCB	442A126
Bridge Signal Conditioning	10	Pacific	9355
Control system DAS:			
HP PC Computer	1	HP	MVAX
HP VXI System Mainframe	1	HP	E8408A
HP VXI Interface	1	HP	E8491B
HP 8-Channel Digitizer + DSP	1	HP	VT1433B
M+P International Acoustic Control Software	1	M+P	Version 2.7.2
Auxiliary DAS:			
MTS Master Series Software (IDEAS)	1	MTS	Version 10
PC computer	1	HP	TAFA-ACQ
HP VXI System Mainframe	1	HP	E8403A
HP VXI Interface	1	HP	E8491B
HP 16-Channel Digitizer	4	HP	1432A

The layout of the reverberation room for the vibro-acoustic testing of the Flaperon test article is shown in Figure 1-11. The locations of the low-frequency (L3 and L4), the mid-frequency (L1 and L2), and the high-frequency (L5-L10) acoustic drivers are indicated in Figure 1-11. The locations of the control microphones (Mic1-Mic6) around the test article support structure in the center of the chamber are also specified. The height of each microphone is indicated next to its identification, e.g., the height of microphone 1 is 77 inches off the floor.

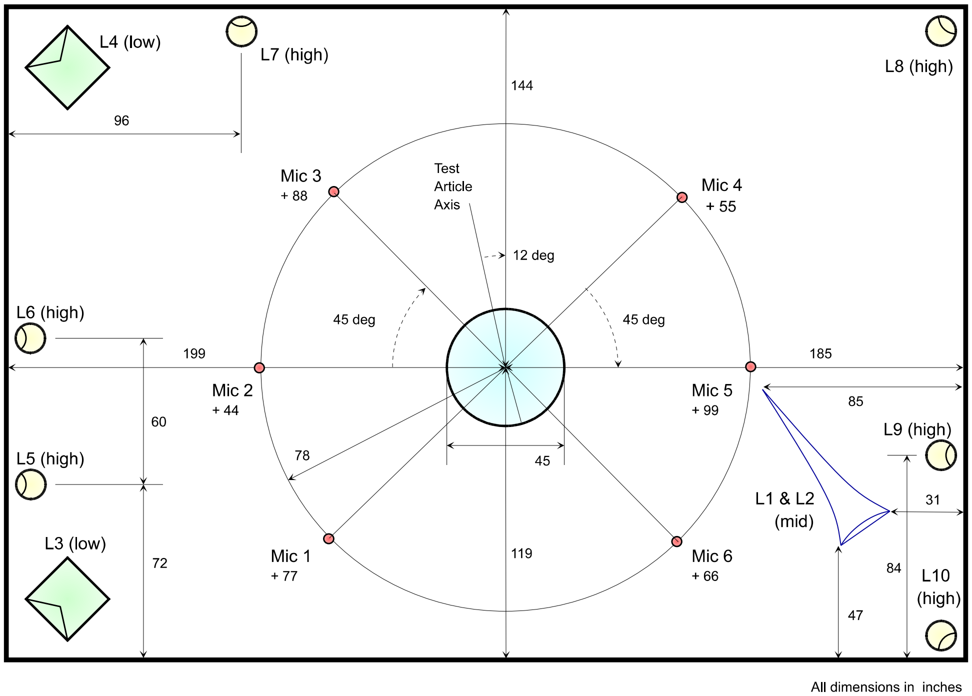

Figure 1-11: Acoustic drivers and control microphones in the reverberation room.

1.7 Dynamic Response Test Description

The dynamic response tests were conducted in the reverberation room of the SALT facility located in Building 1208. The Flaperon was exposed to a specified one-third octave band acoustic spectrum generated from a bounding of acoustic spectra derived from the Atlas V and Delta IV launch environments for a specified duration. The X-37 enveloped spectrum represents an overall sound pressure level (OASPL) of 140.8 dB. Acoustic spectrum shape and level control was performed using the one-third octave band control system. Data acquisition included acoustic data from the microphones (control) in the reverberation room, and accelerometers and strain gages (measurement response) on the test article.

1.7.1 Acoustic Test Level

This specified one-third octave band acoustic spectrum was developed from a bounding envelope of the spectra derived from Atlas V and Delta IV launch environments for one minute as shown in Table 1-6. The last column in Table 1-6 was the X-37 acoustic test spectrum requested for the test.

Table 1-6: X-37 one-third-octave band acoustic loads.

1/3 Octave Band Center Frequency (Hz)	Atlas V (5m Composite Faring, 95/50, 50% fill) [dB]	Delta IV M+ (5m Composite Faring, 95/50, 60% fill) [dB]	X-37 [dB]
31.5	124.5	123	124.5
40	127	126	127
50	128.3	128	128.3
63	129.5	129.5	129.5
80	130	130.5	130.5
100	130.5	130.5	130.5
125	130.5	130.5	130.5
160	130.2	130.5	130.5
200	129.5	130.5	130.5
250	129	130.5	130.5
315	128	130	130
400	126.5	128	128
500	125.5	126	126
630	124.5	123	124.5
800	123	121	123
1000	121.5	119	121.5
1250	120	117.5	120
1600	118	116	118
2000	116	115	116
OASPL=	140.3	140.6	140.8

The acoustic test spectrum is graphically depicted in Figure 1-12.

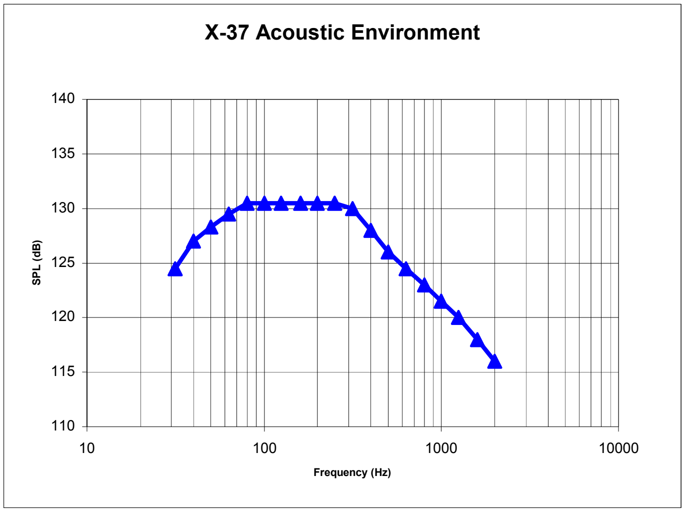

Figure 1-12: Graphical representation of the one-third-octave band acoustic loads.

1.7.2 Acoustic Excitation Test Schedule

The test procedures document (Reference 1-2) stipulates an acoustic excitation applied according to the test schedule indicated in Table 1-7. The shape of the acoustic spectrum was identical for each step according to that specified in Table 1-6. For each level, excitation and response data were acquired. Between each applied level, the data were reviewed to ascertain data integrity and to help set up instrumentation for the next level. In addition, the test article was visually inspected between major runs.

Table 1-7: Initial X-37 acoustic test schedule.

Acoustic Test Run Number	OASPL (dB)	Delta dB Relative to 100% Level (dB)	Duration (s)
1	132	-8.8	30
2	135	-5.8	30
3	138	-2.8	30
4	140.8	0	60

A redline change to the excitation test schedule (Section 10.1.2, Reference 1-2) was made prior to the start of the test, changing the number of runs from four to two, as indicated in Table 1-8.

Table 1-8: Redline X-37 acoustic test schedule.

Acoustic Test Run Number	OASPL (dB)	Delta dB Relative to 100% Level (dB)	Measurement (Y/N)
	128.8	-12	Y
1	131.8	-9	Y
	134.8	-6	Y
	128.8	-12	N
	131.8	-9	N
	134.8	-6	Y
2	137.8	-3	Y
	140.8	0	Y
	134.8	-6	Y
	128.8	-12	Y

1.8 Acoustic Control System

The acoustic control system consisted of a personal computer, running 1/3-octave band control software from M+P, and a VXI-based front-end (Figure 1-13). The control system output was routed to a crossover filter to split the output signal into low-, middle-, and high-frequency ranges. Following amplification, these were routed to acoustic drivers, the combined output of which was measured by six (6) control microphones. A frequency control region was programmed for each of the acoustic driver types by setting the high-pass and low-pass frequencies along with filter and slope specifications. The three-way crossover settings for all tests are listed in Table 1-9.

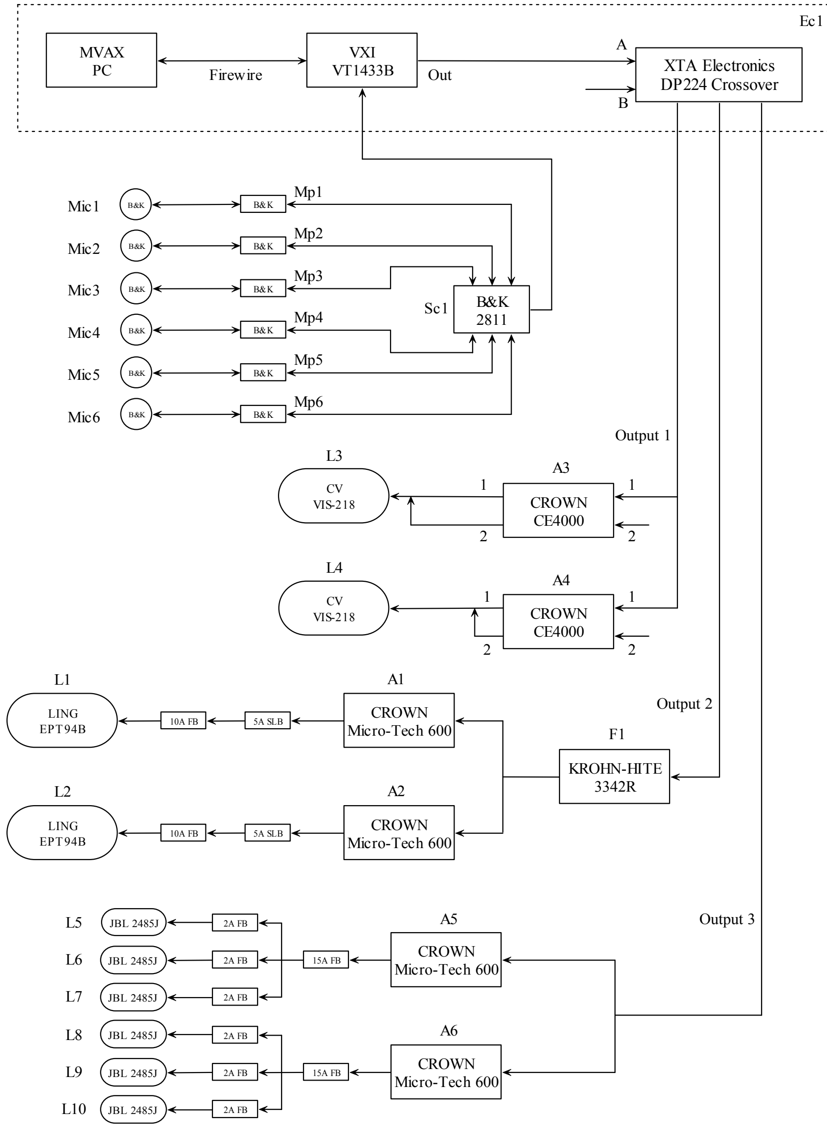

Figure 1-13: Schematic of acoustic control system configuration.

Table 1-9: DP224 three-way crossover settings.

Acoustic Driver	High-Pass Frequency	Filter	Slope	Low-Pass Frequency	Filter	Slope
	[Hz]		[dB/octave]	[Hz]		[dB/octave]
Subwoofer	13.9	Link/Riley	24	120	Butterworth	18
Pneumatic horn	80.3	Butterworth	18	2000	Link/Riley	24
Compression driver	794	Butterworth	24	5040	Butterworth	24

A graphical representation of the different control regions is shown in Figure 1-14.

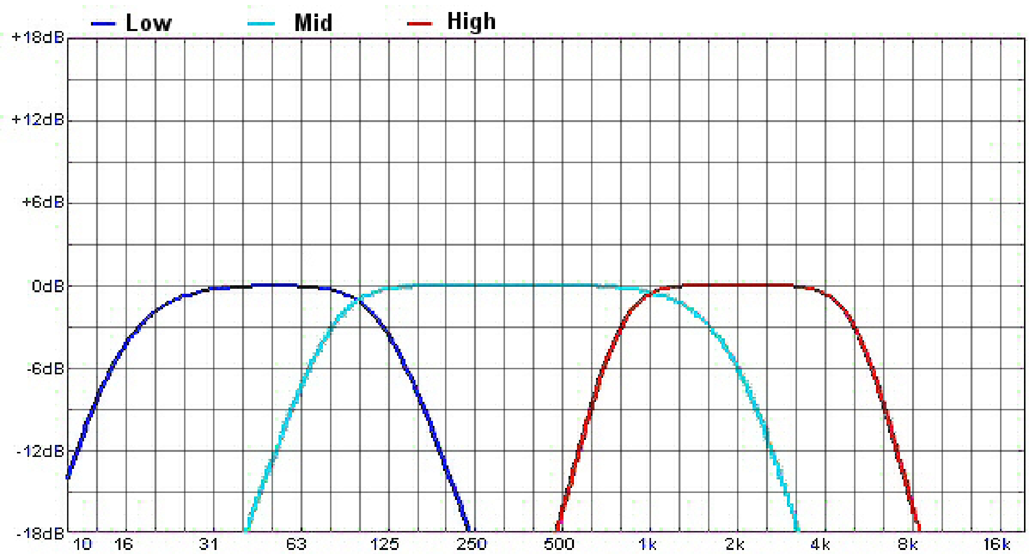

Figure 1-14: The control regions for low-, mid-, and high-frequency acoustic drivers.

The acoustic control system operated on a 1/3-octave basis to provide the test control requirements listed in Table 1-10. From these requirements and the test spectrum indicated in Table 1-6, control parameters used for the test were developed and are listed in Table 1-11.

Table 1-10: Measurement setup parameters.

Measurement Parameter	Acoustic Test
Minimum 1/3-Octave Band Analysis Bandwidth	50 – 2000 Hz
Minimum Spectral Resolution	1/3-Octave
Overall Sound Pressure Level	+3 dB, -1 dB
Control Tolerance (50-2000Hz 1/3-Octave Band)	+4 dB, -2 dB

Table 1-11: Control parameters and limits used in acoustic control system.

1/3 Octave Band Center Frequency [Hz]	Root-Mean-Square Sound Pressure Level [dB]	Alarm [dB]	Alarm [dB]	Abort [dB]
40	127	-3	3	6
50	128.3	-2	4	6
63	129.5	-2	4	6
80	130.5	-2	4	6
100	130.5	-2	4	6
125	130.5	-2	4	6
160	130.5	-2	4	6
200	130.5	-2	4	6
250	130.5	-2	4	6
315	130	-2	4	6
400	128	-2	4	6
500	126	-2	4	6
630	124.5	-2	4	6
800	123	-2	4	6
1000	121.5	-2	4	6
1250	120	-2	4	6
1600	118	-2	4	6
2000	116	-2	4	6
OASPL	140.67	-1	1	3

Advanced control system parameters, indicated in Table 1-12, were set to abort the test when criteria were exceeded or not met.

Table 1-12: Advanced measurement setup parameters.

Advanced Control Parameters		
Time constant	1.0	[s]
Maximum number of octave bands tolerated in abort	5	
Maximum time octave bands can be in abort	5.0	[s]
Maximum time overall sound pressure level (OASPL) can be in abort	10.0	[s]
Maximum microphones can deviate from average	6.0	[dB]
Maximum time microphones can deviate	10.0	[s]
Minimum number of valid microphones	3	

1.9 Data Acquisition System

The auxiliary data acquisition and acoustic control systems are shown in Figure 1-15. The auxiliary data acquisition system (DAS) consists of a personal computer running MTS IDEAS and a VXI-based front-end. The DAS is used to acquire response data from strain gages and accelerometers mounted on the test article. In addition, the DAS is used to record the acoustic excitation measured by the control microphones. The channels used for the DAS are referenced in Table 1-13. Channel 64 was not used.

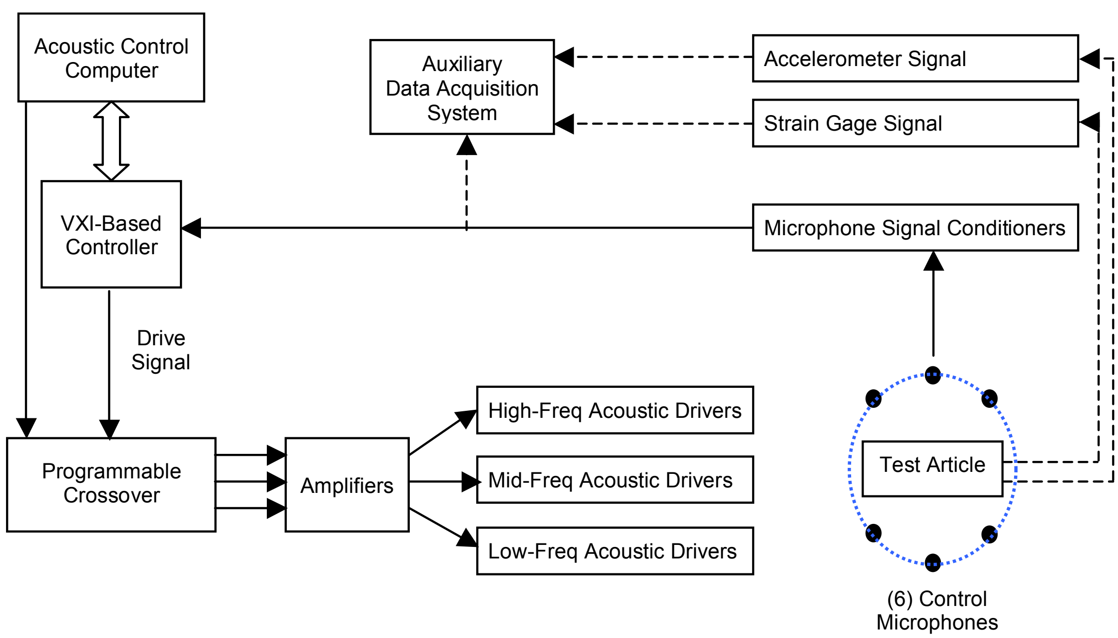

Figure 1-15: Auxiliary data acquisition and acoustic control system configuration.

Table 1-13: IDEAS channel identification numbers, associated transducers and their serial numbers.

Channel	Transducer	#	Serial #	Channel	Transducer	#	Serial #	Channel	Transducer	#	Serial #
1	Accelerometer	3	11714	22	Accelerometer	16	18416	43	Accelerometer	47	11078
2	Accelerometer	6	18402	23	Accelerometer	17	18418	44	Accelerometer	45	11113
3	Accelerometer	9	18407	24	Accelerometer	19	18420	45	Accelerometer	46	11120
4	Accelerometer	10	18408	25	Accelerometer	20	18421	46	Accelerometer	28	14160
5	Accelerometer	12	18411	26	Accelerometer	37	14415	47	Accelerometer	48	11083
6	Accelerometer	13	18412	27	Accelerometer	23	AF818	48	Accelerometer	49	11096
7	Accelerometer	15	18415	28	Accelerometer	25	11077	49	Foil strain gage	51	N/A
8	Accelerometer	18	18419	29	Accelerometer	29	14180	50	Foil strain gage	52	N/A
9	Accelerometer	21	4159	30	Accelerometer	27	14121	51	Foil strain gage	53	N/A
10	Accelerometer	24	1114	31	Accelerometer	1	11710	52	Foil strain gage	54	N/A
11	Accelerometer	7	18405	32	Accelerometer	31	14205	53	Foil strain gage	55	N/A
12	Accelerometer	22	ET79	33	Accelerometer	32	14206	54	Foil strain gage	56	N/A
13	Accelerometer	44	ET40	34	Accelerometer	33	14208	55	Foil strain gage	57	N/A
14	Accelerometer	38	18413	35	Accelerometer	34	14363	56	Foil strain gage	58	N/A
15	Accelerometer	4	11713	36	Accelerometer	2	11711	57	Foil strain gage	59	N/A
16	Accelerometer	5	18399	37	Accelerometer	36	14414	58	Microphone	1	1854456
17	Accelerometer	26	18418	38	Accelerometer	30	14183	59	Microphone	2	489484
18	Accelerometer	8	18406	39	Accelerometer	35	14364	60	Microphone	3	489489
19	Accelerometer	11	18410	40	Accelerometer	39	11111	61	Microphone	4	1854447
20	Accelerometer	14	18413	41	Accelerometer	42	AF806	62	Microphone	5	1854444
21	Accelerometer	50	12858	42	Accelerometer	43	DD43	63	Microphone	6	1854446

The DAS was set up to acquire power spectral density (PSD) data for each channel. All data acquired via the DAS system are stored in engineering units in the English system of units. Calibration and amplification information provided throughout this report are therefore for reference only. They do not need to be applied to the data. Acceleration PSD data are provided in units of $(in/s^2)^2/Hz$. Strain PSD data are provided in units of $(\mu\varepsilon)^2/Hz$. Microphone PSD data are provided in units of $(lbf/in^2)^2/Hz$.

1.10 Test Preparation Procedures

1.10.1 Facility Preparation

It was determined that the facility was ready for operations. All appropriate instrumentation was verified to be available, in calibration if required and in working condition. Facility-lifting devices were certified for operations. The test article and the acoustic support structure in the reverberation chamber were installed in accordance with the test procedures document (Reference 1-2).

1.10.2 Test Article Preparation

The test article was certified ready for test operations by confirming the proper installation of the test article and support structure in the reverberation chamber in accordance with the test procedures document (Reference 1-2). No loose or damaged hardware items were encountered and all sensor mounting locations were accessible.

1.10.3 Test Equipment and Instrumentation Preparation

The correct configuration of the excitation sources and the position of the six-control microphones around the test article in the reverberation chamber were verified. The layout of the reverberation room is depicted in Figure 1-11. The configuration of the instrumentation was verified as specified in the test procedures document (Reference 1-2) and Figure 1-13. Photographs were taken of the pedestal mounted test article and the acoustic equipment in the reverberation chamber. Temperature (70° F), static pressure (1020 mb), and humidity (48%) in the reverberation room were recorded. A redline change was approved and implemented to use all Bruel & Kjaer 4133 model microphone cartridges instead of a mixture of models 4134 and models 4133. The six control microphones were calibrated in accordance with the in-house calibration procedure described in LMS-TD-0558. The calibration values are listed in Table 1-14.

Table 1-14: Control microphone calibrations.

Microphone Calibrations	[mv/Pa]	[mv/psi]
Microphone 1	11.00	75845.00
Microphone 2	11.04	76120.80
Microphone 3	11.03	76051.85
Microphone 4	11.76	81085.20
Microphone 5	11.09	76465.55
Microphone 6	12.19	84050.05

The calibration values were entered in the acoustic control system and the auxiliary DAS. An initial gain factor of 10 was applied to the accelerometer signals and low-pass filters were set to 20 kHz. A gain factor of 1000 was applied to the strain gages and low-pass filters were set to 10 kHz.

It was verified that the correct control parameters were set up. The valves in the reverberation room for the pressurized air to the pneumatic horn were opened in preparation for testing. The instrumented test article was visually inspected and found ready for testing. The double doors of the reverberation room were closed. The pressurized air was switched on allowing flow to the reverberation room. The air pressures for both lines were recorded as 36 psi.

1.11 Dynamic Response Testing

All test runs were performed 24 February 2004.

Acoustic Run 1:
Start time: 9:40:08 am
Start level: -12 dB:
    Power spectra data stored in IDEAS file “acoustic_12_1.afu”
Start level: -9 dB:
    Power spectra data stored in IDEAS file “acoustic_9_1.afu”
Start level: -6 dB:
    Power spectra data stored in IDEAS file “acoustic_6_1.afu”

Control system log file stored in file “protocol_csicflap_runall_001”
Microphone control system data stored in file “data_csicflap_runall_001”
Stop time: 9:48:36

The run was aborted and the data were checked for quality and integrity. It was decided to increase the number of averages for each acquisition from 30 to 50. The test article and instrumentation were visually checked. The microphone control data were checked to insure compliance with the measurement setup parameters in Table 1-10 and Table 1-11. Spectral plots of the control data channels were printed. Acoustic system setup and test parameters were attached.

Acoustic Run 2 (attempt 1):
Start time: 10:23:43 am
Start level: -12 dB:
No IDEAS acquisition
Start level: -9 dB:
No IDEAS acquisition
Start level: -6 dB:
Power spectra data stored in IDEAS file “acoustic_6_2.afu”
Start level: -3 dB:
Power spectra data stored in IDEAS file “acoustic_3_2.afu”
Start level: 0 dB:
Control system log file stored in file “protocol_csicflap_runall_002”
Microphone control system data stored in file “data_csicflap_runall_002”
Stop time: 10:37:11

The test run was aborted due to accelerometer saturation on several channels. The accelerometer gain was changed from 10 to 1 on the signal conditioning units and DAS for all channels and all subsequent runs.

Acoustic Run 2 (attempt 2):
Start time: 10:44:02 am
Start level: -12 dB:
No IDEAS acquisition
Start level: -9 dB:
No IDEAS acquisition
Start level: -6 dB:
Power spectra data stored in IDEAS file “acoustic_6_3.afu”
Start level: -3 dB:
Power spectra data stored in IDEAS file “acoustic_3_3.afu”
Start level: 0 dB:
Control system log file stored in file “protocol_csicflap_runall_003”
Microphone control system data stored in file “data_csicflap_runall_003”
Stop time: 10:52:49

Test aborted due to IDEAS software lockup during auto-range at 0 dB level. Strain gage 54 was found defective but the MR&D representative decided to continue the tests. The two IDEAS data files above were (re)associated within IDEAS. The air to the reverberation chamber was shut down and the doors were opened. The test article and instrumentation were visually inspected and approved for further testing. The doors were closed and the air to the chamber was opened.

Acoustic Run 2 (attempt 3):
Start time: 11:07:21 am
Start level: -12 dB:
    No IDEAS acquisition
Start level: -9 dB:
    No IDEAS acquisition
Start level: -6 dB:
    Power spectra data stored in IDEAS file "acoustic_6_4.afu"
Start level: -3 dB:
    Control system log file stored in file "protocol_csicflap_runall_004"
    Microphone control system data stored in file "data_csicflap_runall_004"
Stop time: 11:13:12

Test aborted due to microphone 5 overload. The air to the reverberation chamber was shut down, the doors were opened, and microphone 5 preamplifier and cartridge were checked and recalibrated. The calibration was successful. The doors were closed and the air to the chamber was opened.

Acoustic Run 2 (attempt 4):
Start time: 11:13:44 am
Start level: -12 dB:
    No IDEAS acquisition
Start level: -9 dB:
    No IDEAS acquisition
Start level: -6 dB:
    No IDEAS acquisition
Start level: -3 dB:
    Control system log file stored in file "protocol_csicflap_runall_005"
    Microphone control system data stored in file "data_csicflap_runall_005"
Stop time: 11:18:29

Test aborted due to microphone 5 overload.

Acoustic Run 2 (attempt 5):
Start time: 11:22:10 am
Start level: -12 dB:
    No IDEAS acquisition
Start level: -9 dB:
    No IDEAS acquisition

Start level: -6 dB:
No IDEAS acquisition
Start level: -3 dB:
Control system log file stored in file "protocol_csicflap_runall_006"
Microphone control system data stored in file "data_csicflap_runall_006"
Stop time: 11:29:38

Test aborted due to microphone 5 overload. A time domain preview on IDEAS showed the signal to varying widely. Microphone 5 was subsequently taken out of the control system, leaving control with microphones 1-4 and 6.

Acoustic Run 2 (attempt 6):
Start time: 11:33:55 am
Start level: -12 dB:
No IDEAS acquisition
Start level: -9 dB:
No IDEAS acquisition
Start level: -6 dB:
Power spectra data stored in IDEAS file "acoustic_6_5.afu"
Start level: -3 dB:
Power spectra data stored in IDEAS file "acoustic_3_5.afu"
Start level: 0 dB:
Power spectra data stored in IDEAS file "acoustic_0_5.afu"
Start level: -6 dB:
Power spectra data stored in IDEAS file "acoustic_6d_5.afu"
Start level: -12 dB:
Power spectra data stored in IDEAS file "acoustic_12d_5.afu"
Control system log file stored in file "protocol_csicflap_runallno5_001"
Microphone control system data stored in file "data_csicflap_runallno5_001"
Stop time: 11:48:31

The air pressure for both lines to the Ling drivers was recorded as 28 psi.

Background noise measurement (with air supply on):
Power spectra data stored in IDEAS file "acoustic_air_5.afu"

Strain gage 54 still malfunctioned. A subsequent check indicated a poor connection of the bridge completion resistor. Accelerometer 14 was found not working. A subsequent check indicated a loose connection at the breakout box. Microphone 5 still produced erratic readings. Drive signal and amplification were turned off for all sources. Air to the Ling drivers was closed and shut down. The reverberation chamber doors were opened and the test article and instrumentation were visually inspected. The microphone control data were checked to insure compliance with the measurement setup parameters in Table 1-10 and Table 1-11. Spectral plots of the control data channels were printed. Acoustic system setup and test parameters were attached.

Temperature (70° F), static pressure (1018 mb), and humidity (29%) in the reverberation room were recorded.

It was verified that the acoustic test of the Flaperon test article had successfully been completed.

1.12 Data Reporting

The VcpNT.ini file is provided in text format and contains the initialization settings for the vibration/acoustic control system. The acoustic control system protocol and data files are provided in ASCII (American Standard Code for Information Interchange) format. The protocol files contain the time logs of all test related events. Starting time of each acoustic level change and times at which measurement data were taken are included. The measurement data are in the control files and include the control, error, drive, and the six microphone spectra on a 1/3-octave band basis. All IDEAS test data for the accelerometers, strain gages, and microphones are available in electronic form in universal and spreadsheet formats. Photographic documentation of the test is provided in TIFF (Tagged Image File Format) in the form of 18 picture files of the test setup in the reverberation chamber. File names of the electronic data are listed in Table 1-15. Data files were saved according to the channel numbers in Table 1-13. Files were archived on compact disk.

Table 1-15: List of compact disk archived protocol, control, and IDEAS data files for all test runs.

Run	Protocol file	Control file	Universal data file	Spreadsheet data file
	VcpNT.ini			
1	protocol_csicflap runall_001.txt	data_csicflap runall_001.txt	acoustic_12_1.unv acoustic_9_1.unv acoustic_6_1.unv	acoustic_12_1.rpt acoustic_9_1.rpt acoustic_6_1.rpt
2/1	protocol_csicflap runall_002.txt	data_csicflap runall_002.txt	acoustic_6_2.unv acoustic_3_2.unv	acoustic_6_2.rpt acoustic_3_2.rpt
2/2	protocol_csicflap runall_003.txt	data_csicflap runall_003.txt	acoustic_6_3.unv acoustic_3_3.unv	acoustic_6_3.rpt acoustic_3_3.rpt
2/3	protocol_csicflap runall_004.txt	data_csicflap runall_004.txt	acoustic_6_4.unv	acoustic_6_4.rpt
2/4	protocol_csicflap runall_005.txt	data_csicflap runall_005.txt		
2/5	protocol_csicflap runall_006.txt	data_csicflap runall_006.txt		
2/6	protocol_csicflap runallno5_001.txt	data_csicflap runallno5_001.txt	acoustic_6_5.unv acoustic_3_5.unv acoustic_0_5.unv acoustic_6d_5.unv acoustic_12d_5.unv acoustic_air_5.unv	acoustic_6_5.rpt acoustic_3_5.rpt acoustic_0_5.rpt acoustic_6d_5.rpt acoustic_12d_5.rpt acoustic_air_5.rpt

1.13 References

1-1 Grosveld, Ferdinand W., "Calibration of the Structural Acoustic Loads and Transmission (SALT) Facility at NASA Langley Research Center," presented at the INTER-NOISE 99 International Congress on Noise Control Engineering, Fort Lauderdale, Florida, 6-8 December 1999.

1-2 Rice, Chad E., "X-37 Hot-Structures Control Surface, Carbon-Silicone Carbide Flaperon Control Surface – Modal, Vibration, and Acoustics Test Procedures," NASA Langley Research Center, Hampton, Virginia, 11 February 2004.

1-3 Vibration Test Instrument Schematic, MR&D Drawing No. GE03-2.1.2-802.

2. C-C Ruddervator

2.1 Introduction

Science Applications International Corporation (SAIC), under subcontract to The Boeing Company, is developing improved control surface structures for the Advanced Technology Vehicle (ATV) that will be flight-tested as part of the X-37 Orbital Vehicle Program. The Boeing X-37 vehicle incorporates a hot structure "Ruddervator" control surface, made from oxidation-protected carbon-carbon (C-C), which will be subjected to vibratory and acoustic loads from the lift-off mission phase of flight. A subcomponent design for the C-C Ruddervator was developed and manufactured. The goal of the hot structure Ruddervator control surface vibro-acoustics tests is to simulate the dynamic response of the C-C Ruddervator subcomponent when subjected to excitation loads corresponding to the lift-off environment, but at room temperatures. Measured responses will be compared to predicted strains and accelerations to determine the validity of the mathematical model for this C-C subcomponent test article. This report covers the vibro-acoustic testing in the reverberation chamber of the Structural Acoustics Loads and Transmission (SALT) facility (Reference 2-1) at NASA Langley Research Center.

2.2 Acoustic Test Objective

The objective of the acoustic test is to measure the dynamic response of the C-C Ruddervator subcomponent when subjected to the acoustic loads corresponding to an envelope of the Atlas V and Delta IV launch environments. The measured responses (acceleration and strain) will be used to assess the construction techniques and mathematical model using a stochastic acoustic input that replicates the launch environment of the X-37 vehicle. This document describes the test article, the facility configuration, test setup, instrumentation, acoustic test loads spectra, test sequence, acoustic control and data acquisition systems, test results, and the data reporting of the C-C Ruddervator subcomponent.

2.3 Test Article

The C-C Ruddervator subcomponent test article consists of carbon-carbon composite materials fabricated by Carbon-Carbon Advanced Technologies, Inc. The subcomponent test article (STA) is a truncated full-scale replica of the flight hardware that incorporates all major structural components, such as the spindle, attachment joints, and ribs. The overall dimensions of the test article are 37.5 inches span-wise from the inboard edge to the leading edge and 19.7 inches along the trailing edge. The width of the test article at the base is 33.55 inches. A picture of the C-C Ruddervator test article without the spindle is shown in Figure 2-1.

Figure 2-1: C-C Rudderator test article without spindle.

The test article was mounted on a steel interface plate as shown in the sketch of Figure 2-2. A support structure (Figure 2-3) was bolted to the floor of the reverberation chamber and filled with sand. The support structure was used to elevate the test article for better exposure to the acoustic excitation loads. The test article and steel interface plate were mounted to the top of the support structure. The test procedures document in Reference 2-2 provides the details on the designs, the drawings, and test setup installation procedures of the test article and support structure.

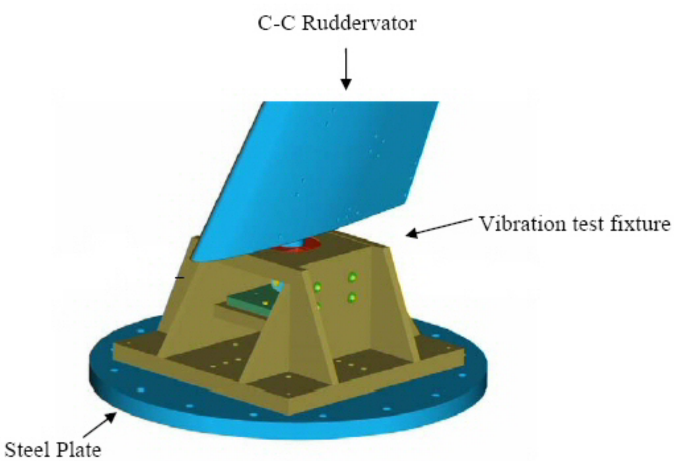

Figure 2-2: Test article and steel interface plate.

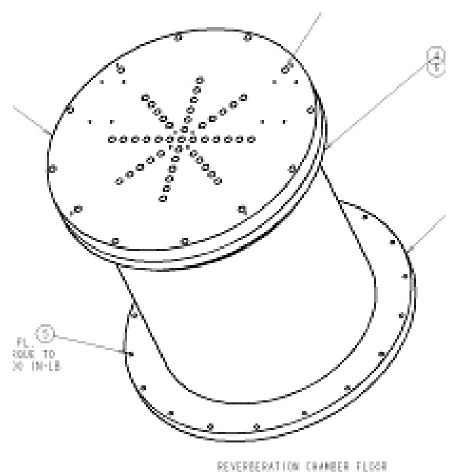

Figure 2-3: Test article support structure.

2.4 Test Article Instrumentation

The instrumentation sensor suite consisted of twelve accelerometers and twelve foil strain gage sensors. Figure 2-4 shows the twelve accelerometers locations in four tri-axial configurations. Small 0.02 oz, 10 mV/g, PCB 352C22 accelerometers were used for these tests. The tri-axial configurations were achieved using an accelerometer mounting block. The weight of the mounting block was typically 0.08 oz. The X, Y, and Z coordinate axes for the accelerometers are shown in Figure 2-5.

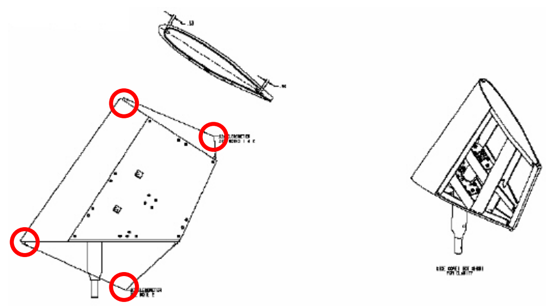

Figure 2-4: Locations of the four tri-axial accelerometers.

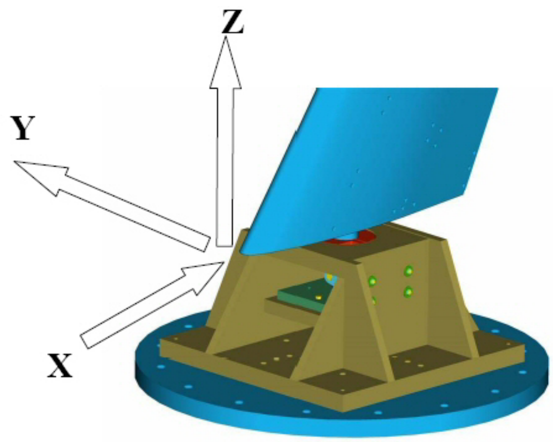

Figure 2-5: Coordinate axes for the accelerometers.

Table 2-1 lists the accelerometer channels, serial numbers, sensitivities, orientations, and locations.

Table 2-1: Accelerometer channels, serial numbers, sensitivities, orientations, and locations.

Accelerometer	Serial Number	Sensitivity [mV/g]	Orientation	Location/position
A3	18405	9.557	-z	bottom leading edge
A4	18420	9.888	-y	bottom leading edge
A5	18421	10.07	-x	bottom leading edge
A6	18412	10.42	y	bottom trailing edge
A7	18413	9.977	-z	bottom trailing edge
A8	18415	9.960	-x	bottom trailing edge
A9	18419	9.760	-y	top leading edge
A10	18408	9.660	z	top leading edge
A11	18410	10.17	-x	top leading edge
A12	18411	9.610	z	top trailing edge
A13	18416	9.885	y	top trailing edge
A14	18418	9.812	-x	top trailing edge

The locations of the four foil strain gage rosettes are shown in Figure 2-6. The instrumented test article during the controlled acoustic excitation tests in the reverberation chamber is shown in Figure 2-7. Locations and orientations of the strain gages are provided in Reference 2-2.

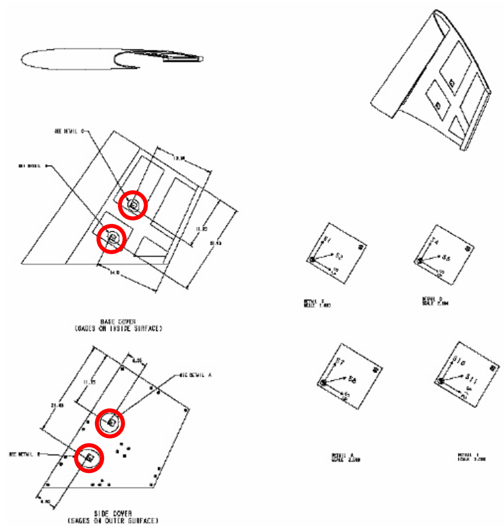

Figure 2-6: Locations of the four foil strain gage rosettes.

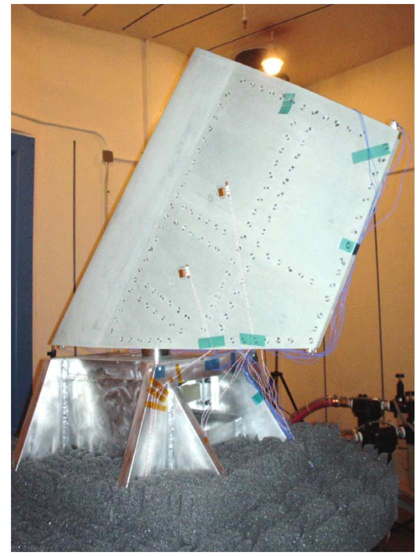

Figure 2-7: Instrumented test article in the reverberation chamber.

2.5 Acoustic Test Facility

The 9800 ft^3 SALT facility reverberation chamber (Reference 2-1) measures approximately 14.8 ft by 21.2 ft by 31.2 ft and is structurally isolated from the rest of the building. Figure 2-8 shows the reverberation chamber with the instrumented test article mounted on the sand-filled pedestal support. Rigid close-out panels were installed in the transmission loss window (separating the reverberation chamber from the anechoic chamber) and the flow duct (not shown in the picture). The chamber walls and ceiling of the reverberation chamber are splayed to diminish the effects of standing waves between opposite surfaces and are separated by a 30-inch air gap from the surrounding 18-inch thick concrete building walls. The total surface area of the walls, floor, and ceiling is approximately 3120 ft^2. One-third octave band ambient noise levels were measured previously (Reference 2-1) in the reverberation chamber and are listed in Table 2-2. The minimum frequency for a diffuse sound field in the reverberation chamber was calculated to be 83.2 Hz yielding the one-third octave bands with 100 Hz and higher center frequencies exhibiting diffuse sound conditions (Reference 2-1). Table 2-2 also lists the T(20) reverberation times, the estimated times required for the sound pressure level (SPL) to decrease 60 dB, extrapolated from the SPL decays between –5 dB and –25 dB.

Figure 2-8: Test article mounted on the pedestal support structure in the reverberation chamber.

Table 2-2: Background noise levels and reverberation times in the reverberation room.

One-Third Octave Band Center Frequency [Hz]	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000
Background Noise Level [dB]	34.4	32.1	43.2	27.6	26.9	28.9	22.6	20.7	12.4	12.6	12.3	10.2	9.5	7.6	7
Reverberation Time (T20) [s]	23.3	15.0	13.5	14.2	15.8	15.3	14.9	13.7	12.4	10.8	9.4	8.4	7.0	5.8	5.1

2.6 Test Equipment and Instrumentation

Excitation in the reverberation chamber was provided by three types of acoustic drivers to cover the one-third octave band frequency range from 40 Hz through 2000 Hz. The low frequencies were generated by two subwoofers, the mid-frequencies by a dual-driver pneumatic horn, and the high frequencies were generated by compact compression drivers. Figure 2-9 shows one of the subwoofers and one of the compression drivers in the reverberation chamber. The pneumatic horn in the reverberation chamber is depicted in Figure 2-10.

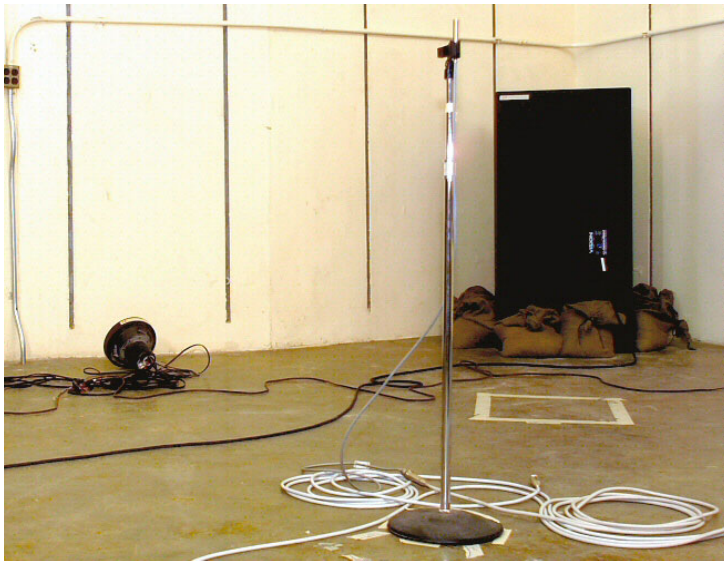

Figure 2-9: The low-frequency subwoofer (right) and high-frequency compression driver (left on the floor).

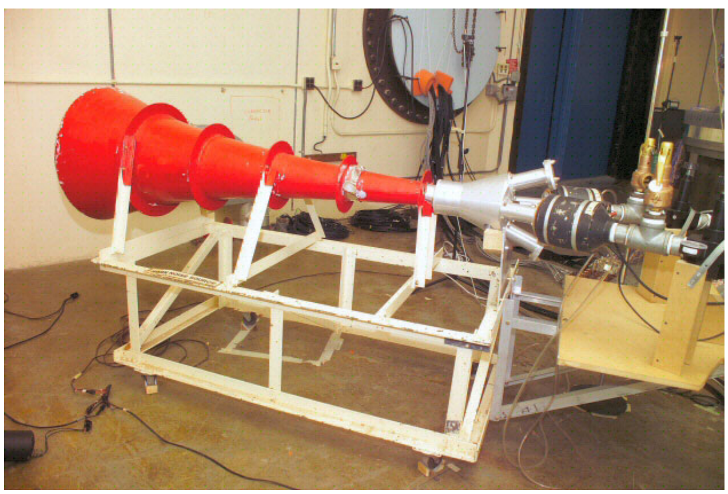

Figure 2-10: The pneumatic horn outfitted with two mid-frequency acoustic drivers.

An acoustic control system used the averaged measured signals of six control microphones to generate the required acoustic spectrum shape inside the reverberation chamber by independently adjusting the input signal to each of the three types of acoustic drivers. The control system will be described in detail in Section 2.8. Descriptions of the acoustic equipment, instrumentation and settings used during the tests, including model, serial number, and calibration information are listed in Table 2-3 and Table 2-4. Other support equipment and instrumentation for installation of the test article and acquisition of the acceleration and strain data are summarized in Table 2-5.

Table 2-3: Acoustic equipment and instrumentation descriptions for the X-37 C-C Ruddervator testing.

A1 **Amplifier** Crown Micro-Tech 600 A019775 Bridge Mono 655 Watts at 8 Ohms Input: XLR 1 Output: +1, +2 Gain: Full	**A2** **Amplifier** Crown Micro-Tech 600 A019774 Bridge Mono 655 Watts at 8 Ohms Input: XLR 1 Output: +1, +2 Gain: Full	**A3 and A4** **Amplifier** Crown CE4000 Bridge Mono 2800 Watts at 4 Ohms Input: XLR 1 Output: +1, +2 Sensitivity: 1.4 V Ch1: Flat low-pass Ch2: N/A Gain: Full
A5 **Amplifier** Crown Micro-Tech 600 A019773 Bridge Mono 655 Watts at 8 Ohms Input: XLR 1 Output: +1, +2 Gain: Full	**A6** **Amplifier** Crown Micro-Tech 600 A019773 Bridge Mono 655 Watts at 8 Ohms Input: XLR 1 Output: +1, +2 Gain: Full	**F1** **Filter** Krohn-Hite 3342R A033067 ECN 429787 Freq 1 Hz High Pass Line Opr Gain: 20 dB Left channel 1 (Front) Right channel not used
Sc1 **8-Channel Multiplexer** Bruel & Kjaer Model 2811 Use: Signal Conditioning Ser: 1607595 ECN: 1090893 Cal due: 5/17/05	**Ec1** **Acoustic Control System** M+P International, Inc. VXI Technology VT1433B input	**Pph1** **Sound Level Calibrator** General Radio 1562-A Nominal: 114.0 dB at 500 Hz Ser: 7960 ECN: A025926 Cal due: 11/10/04
L1 and L2 (mid) **Pneumatic Horn** Ling (2) Model: EPT94B Frequency Range: 100Hz-1000Hz	**L3 and L4 (low)** **Dual 18" Subwoofer** Cerwin Vega (2) Vis-218 Parallel Mode Input Frequency Range: 29Hz-300Hz Peak: 2800 Watts	**L5 - L10 (high)** **Compression Driver** JBL (6) Model: 2485J Frequency Range: 300Hz-6kHz Continuous: 120 Watts

Table 2-4: Microphone and preamplifier specifications.

Mic1 **Microphone** Bruel & Kjaer 4133 Ser: 488997 MCN: A037057 Cal: 05/14/05	**Mic2** **Microphone** Bruel & Kjaer 4133 Ser: 489484 MCN: A037050 Cal: 05/14/05	**Mic3** **Microphone** Bruel & Kjaer 4134 Ser: 173455 MCN: A037055 Cal: 05/14/05	**Mic4** **Microphone** Bruel & Kjaer 4133 Ser: 1854447 MCN: A019642 Cal: 05/14/05	**Mic5** **Microphone** Bruel & Kjaer 4133 Ser: 1854444 MCN: A037051 Cal: 05/14/05	**Mic6** **Microphone** Bruel & Kjaer 4133 Ser: 1854446 MCN: A037053 Cal: 05/14/05
Mp1 **Microphone Preamplifier** Bruel & Kjaer 2619 Ser: 761358 MCN: A004353 Cal: 05/13/05	**Mp2** **Microphone Preamplifier** Bruel & Kjaer 2619 Ser: 1649717 MCN: A004357 Cal: 05/13/05	**Mp3** **Microphone Preamplifier** Bruel & Kjaer 2619 Ser: 692811 MCN: A004354 Cal: 05/13/05	**Mp4** **Microphone Preamplifier** Bruel & Kjaer 2619 Ser: 360362 MCN: A004284 Cal: 05/13/05	**Mp5** **Microphone Preamplifier** Bruel & Kjaer 2619 Ser: 797667 MCN: A004280 Cal: 05/13/05	**Mp6** **Microphone Preamplifier** Bruel & Kjaer 2619 Ser: 521525 MCN: A002640 Cal: 05/13/05

Table 2-5: Test article support equipment and instrumentation.

Description	Quantity	Manufacturer	Model / Part Number
Test article structural support:			
Steel Adaptor Plate	1	AmTech	Drawing # 1256402
Support Structure	1	AmTech	Drawing # 1256401
Vibration sensors:			
Measurement Accelerometers	12	PCB	352C22
Foil Strain Gages (Four Rosettes)	12	Micro-Measurements	CEA-06-250UR-350
Signal conditioning system:			
Chassis/Power supply	1	PCB	442A175 MCM A030131
16-Channel Signal Conditioning	4	PCB	442A126
Bridge Signal Conditioning	12	Pacific	9355
Control system DAS:			
HP PC Computer	1	HP	2100795
HP VXI System Mainframe	1	HP	E8408A
HP VXI Interface	1	HP	E8491B
HP 8-Channel Digitizer + DSP	1	HP	VT1433B
M+P International Acoustic Control Software	1	M+P	Version 2.7.2
Auxiliary DAS:			
MTS Master Series Software (IDEAS)	1	MTS	Version 7
PC computer	1	HP	TAFA-ACQ
HP VXI System Mainframe	1	HP	E8403A
HP VXI Interface	1	HP	E8491B
HP 16-Channel Digitizer	2	HP	1432A

The layout of the reverberation chamber for acoustic testing of the Ruddervator subcomponent test article is illustrated in Figure 2-11. The locations of the low-frequency (L3 and L4), the mid-frequency (L1 and L2), and the high-frequency (L5-L10) acoustic drivers are shown in Figure 2-11. The locations of the control microphones (Mic1-Mic6) around the test article support structure in the center of the chamber are also depicted. The height of each microphone is indicated next to its identification, e.g., the height of Microphone 1 is 77 inches off the floor.

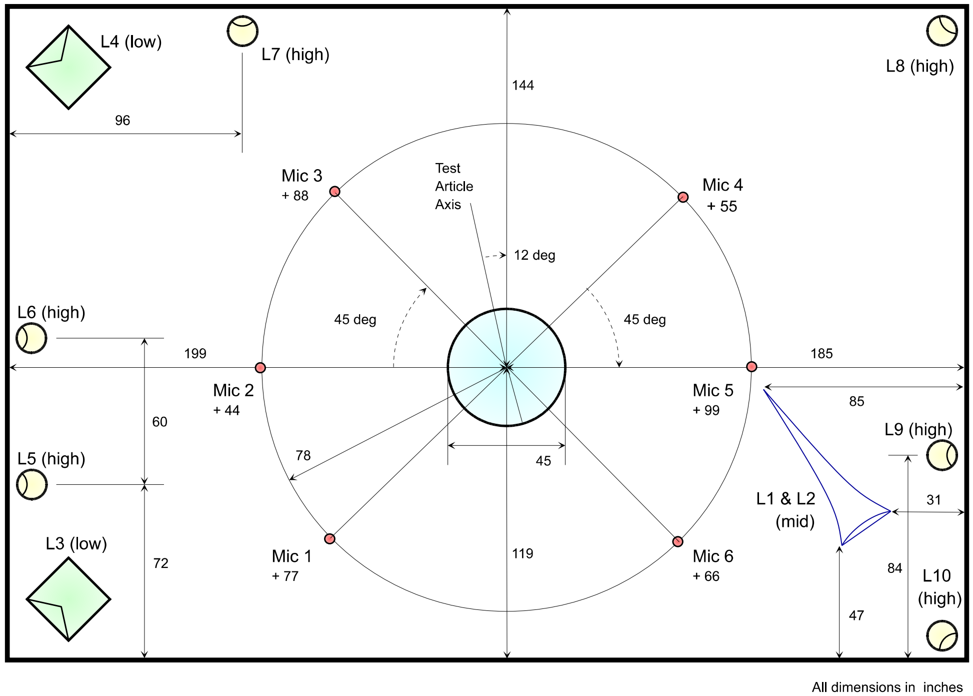

Figure 2-11: Acoustic drivers and control microphones in the reverberation room.

2.7 Dynamic Response Test Description

The Ruddervator was exposed to one-third octave band acoustic excitation derived from a bounding of Atlas V and Delta IV launch environments acoustic spectra. The acoustic spectrum shape and level was produced using a one-third octave band control system. Data acquisition included acoustic data from the six control microphones in the reverberation chamber and accelerometers and strain gages (measurement response) mounted on the test article.

2.7.1 Acoustic Test Level

The one-third octave band acoustic excitation spectra for the Atlas V, Delta IV, and the X-37 are shown in Table 2-6. The X-37 enveloped spectrum represents an overall sound pressure level (OASPL) of 140.8 dB. The acoustic test spectrum is graphically depicted in Figure 2-12. The one-third octave band with a center frequency of 31.5 Hz was not controlled by the acoustic control system in the reverberation chamber test. The OASPL was 140.67 dB with the 31.5 Hz one-third octave band not participating. The acoustic excitation spectrum generated and controlled in the reverberation chamber acoustics test is shown in the last column of Table 2-6.

2.7.2 Acoustic Excitation Test Schedule

The test procedures document (Reference 2-2) stipulates an acoustic excitation applied according to the test schedule listed in Table 2-7. The shape of the acoustic spectrum, specified in the last column of Table 2-6, was identical for all overall sound pressure levels. Excitation and response data were acquired at each level and the data were reviewed to ascertain data integrity. The test article was visually inspected between runs #1 and #2.

Table 2-6: X-37 one-third-octave band acoustic excitation spectra.

One-Third Octave Band Center Frequency [Hz]	Atlas V (5m Composite Faring, 95/50, 50% fill) [dB]	Delta IV M+ (5m Composite Faring, 95/50, 60% fill) [dB]	Bounded X-37 Spectrum [dB]	Reverberation chamber Acoustic Test [dB]
31.5	124.5	123	124.5	
40	127	126	127	127
50	128.3	128	128.3	128.3
63	129.5	129.5	129.5	129.5
80	130	130.5	130.5	130.5
100	130.5	130.5	130.5	130.5
125	130.5	130.5	130.5	130.5
160	130.2	130.5	130.5	130.5
200	129.5	130.5	130.5	130.5
250	129	130.5	130.5	130.5
315	128	130	130	130
400	126.5	128	128	128
500	125.5	126	126	126
630	124.5	123	124.5	124.5
800	123	121	123	123
1000	121.5	119	121.5	121.5
1250	120	117.5	120	120
1600	118	116	118	118
2000	116	115	116	116
OASPL=	**140.3**	**140.6**	**140.8**	**140.67**

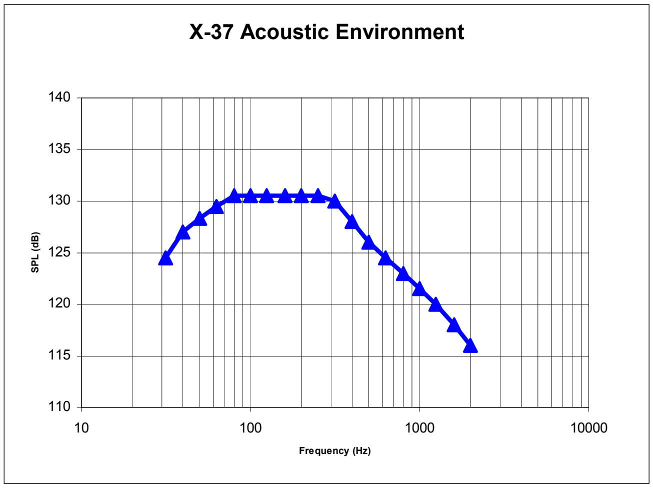

Figure 2-12: Graphical representation of the X-37 one-third octave band acoustic excitation spectrum.

Table 2-7: X-37 acoustic test schedule in the reverberation room.

Acoustic Run #1			Acoustic Run #2		
OASPL [dB]	**Delta dB [dB]**	**Data Acquisition (Y/N)**	**OASPL [dB]**	**Delta dB [dB]**	**Data Acquisition (Y/N)**
128.67	-12	Y	128.67	-12	N
131.67	-9	Y	131.67	-9	N
134.67	-6	Y	134.67	-6	Y
			137.67	-3	Y
			140.67	0	Y
			134.67	-6	Y
			128.67	-12	Y

2.8 Acoustic Control System

The acoustic control system consisted of a personal computer, running one-third octave band control software from M+P, and a VXI-based front-end (Figure 2-13). The control system output was routed to a DP224 three-way crossover filter to split the output signal into low-, middle-, and high-frequency ranges. Following amplification, these were directed to acoustic drivers, the combined output of which was measured by the six control microphones. A frequency control region was programmed for each of the acoustic driver types by setting high-pass and low-pass frequencies along with filter and slope specifications. The three-way crossover settings for all tests are listed in Table 2-8.

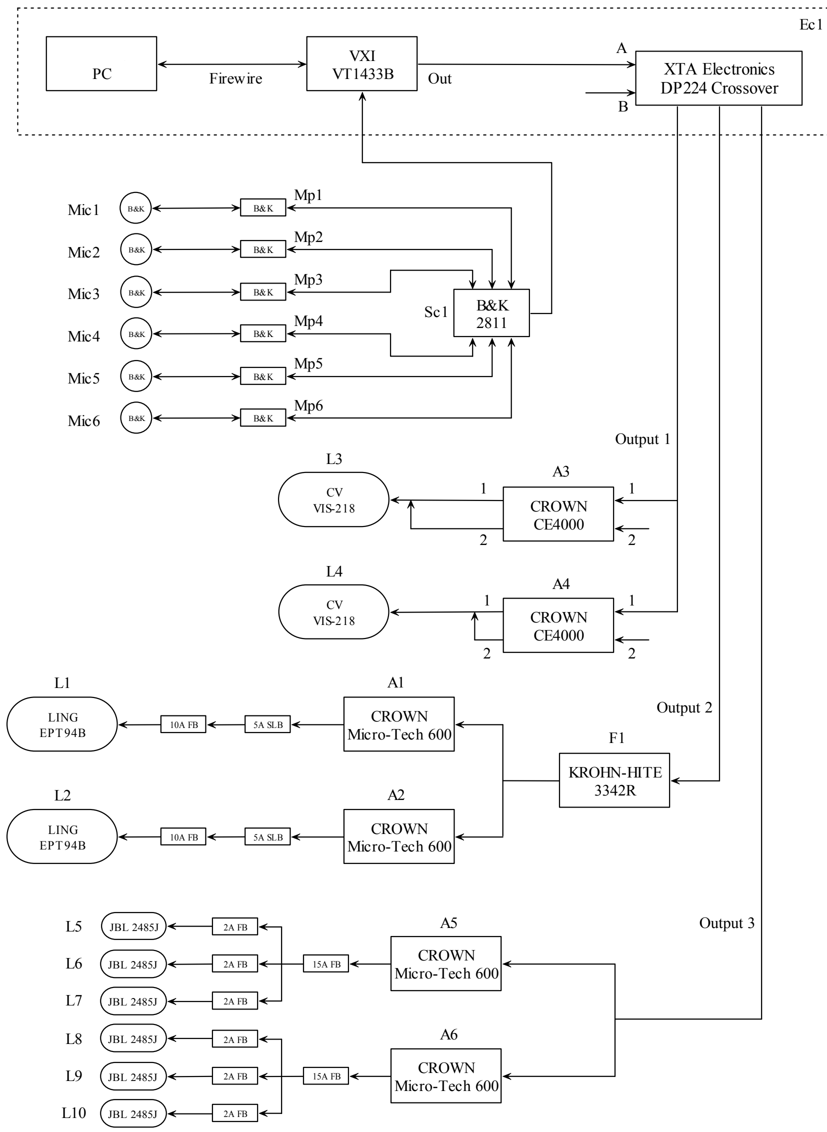

Figure 2-13: Schematic of acoustic control system configuration.

Table 2-8: DP224 three-way crossover settings.

Acoustic Driver	High-Pass Frequency [Hz]	Filter	Slope [dB/octave]	Low-Pass Frequency [Hz]	Filter	Slope [dB/octave]
Subwoofer	13.9	Link/Riley	24	120	Butterworth	18
Pneumatic horn	80.3	Butterworth	18	2000	Link/Riley	24
Compression driver	794	Butterworth	24	5040	Butterworth	24

A graphical representation of the different control regions is shown in Figure 2-14.

Figure 2-14: The control regions for low-, mid-, and high-frequency acoustic drivers.

Measurement setup parameters for the acoustic control system are tabulated in Table 2-9.

Table 2-9: Measurement setup parameters.

Measurement Parameter	Acoustic Test
Minimum one-third octave band analysis bandwidth	40 – 2000 Hz
Minimum spectral resolution	One-third octave
Overall sound pressure level (OASPL)	+1 dB, -1 dB
Control tolerance (40 Hz one-third octave band)	+3 dB, -3 dB
Control tolerance (50-2000 Hz one-third octave band)	+4 dB, -2 dB

Table 2-10 shows the reverberation chamber acoustic test sound pressure levels (listed in the last column of Table 2-6) along with the limits set for the acoustic control system. The advanced control system parameters in Table 2-11 were set to abort the test when those criteria were exceeded.

Table 2-10: Sound pressure levels and limits set in acoustic control system.

One-Third Octave Band Center Frequency [Hz]	Sound Pressure Level [dB]	Low Alarm [dB]	High Alarm [dB]	Abort [dB]
40	127	-3	3	6
50	128.3	-2	4	6
63	129.5	-2	4	6
80	130.5	-2	4	6
100	130.5	-2	4	6
125	130.5	-2	4	6
160	130.5	-2	4	6
200	130.5	-2	4	6
250	130.5	-2	4	6
315	130	-2	4	6
400	128	-2	4	6
500	126	-2	4	6
630	124.5	-2	4	6
800	123	-2	4	6
1000	121.5	-2	4	6
1250	120	-2	4	6
1600	118	-2	4	6
2000	116	-2	4	6
OASPL	140.67	-1	1	3

Table 2-11: Advanced measurement setup parameters.

Advanced Control Parameters		
Time constant	1.0	[s]
Maximum number of octave bands tolerated in abort	5	
Maximum time octave bands can be in abort	5.0	[s]
Maximum time overall sound pressure level (OASPL) can be in abort	10.0	[s]
Maximum microphones can deviate from average	6.0	[dB]
Maximum time microphones can deviate	10.0	[s]
Minimum number of valid microphones	3	

2.9 Data Acquisition System

The auxiliary data acquisition and acoustic control systems are shown in Figure 2-15. The auxiliary data acquisition system (DAS) consisted of a personal computer running MTS IDEAS and a VXI-based front-end. The DAS was used to acquire response data from accelerometers and strain gages mounted on the test article. In addition, the DAS recorded the acoustic excitation measured by the control microphones. The transducer channels operated for the DAS are referenced in Table 2-12. Channels 19, 20, and 32 were not used. The DAS was set up to acquire power spectral density (PSD) data for each channel. All data acquired via the DAS system were stored in engineering units in the English system of units. Calibration and amplification information provided throughout this report are therefore for reference only. They do not need to be applied to the data. Acceleration PSD data are provided in units of $(in/s^2)^2/Hz$. Strain PSD data are provided in units of $(in/in)^2/Hz$. Microphone PSD data are provided in units of $(lbf/in^2)^2/Hz$.

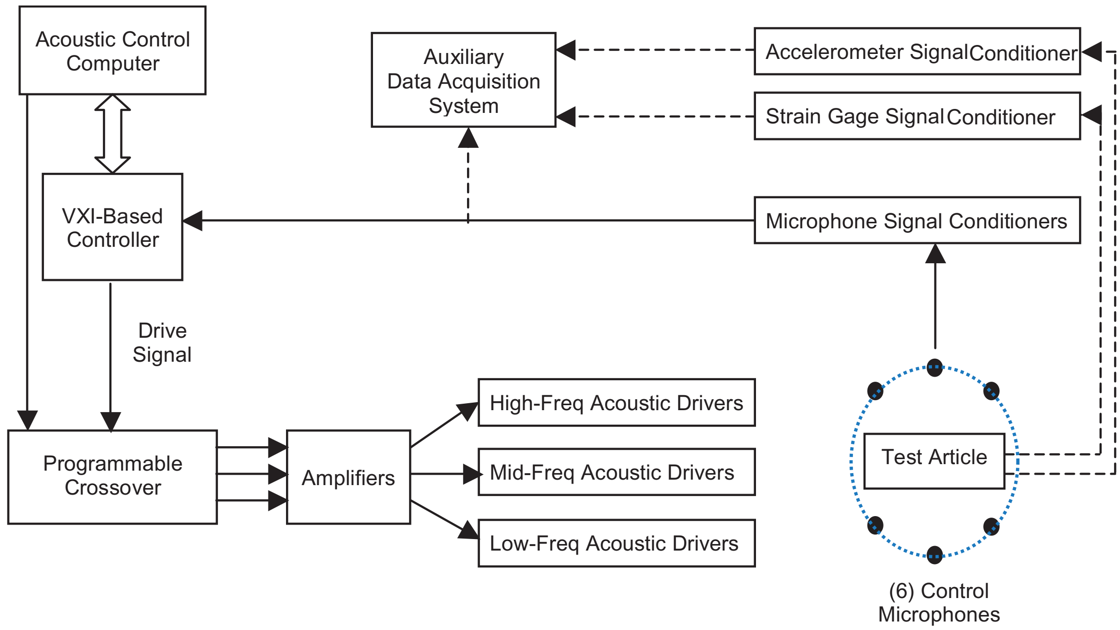

Figure 2-15: Auxiliary data acquisition and acoustic control system configuration.

Table 2-12: IDEAS channel identification numbers, associated transducers, and their serial (MCN) numbers.

Channel	Transducer	#	Serial #	Channel	Transducer	#	Serial #	Channel	Transducer	#	Serial #
1	Accelerometer	A3	18405	12	Accelerometer	A14	18418	23	Foil strain gage	S3	N/A
2	Accelerometer	A4	18420	13	Microphone	M1	488997	24	Foil strain gage	S4	N/A
3	Accelerometer	A5	18421	14	Microphone	M2	489484	25	Foil strain gage	S5	N/A
4	Accelerometer	A6	18412	15	Microphone	M3	173455	26	Foil strain gage	S6	N/A
5	Accelerometer	A7	18413	16	Microphone	M4	1854447	27	Foil strain gage	S7	N/A
6	Accelerometer	A8	18415	17	Microphone	M5	1854444	28	Foil strain gage	S8	N/A
7	Accelerometer	A9	18419	18	Microphone	M6	1854446	29	Foil strain gage	S9	N/A
8	Accelerometer	A10	18408	19	Empty			30	Foil strain gage	S10	N/A
9	Accelerometer	A11	18410	20	Empty			31	Foil strain gage	S12	N/A
10	Accelerometer	A12	18411	21	Foil strain gage	S1	N/A	32	Empty		
11	Accelerometer	A13	18416	22	Foil strain gage	S2	N/A				

2.10 Test Preparation Procedures

2.10.1 Facility Preparation

The reverberation chamber of the SALT facility was prepared for the acoustic testing and declared ready for operations. All appropriate instrumentation was verified to be available, in calibration if required and in working condition. Facility-lifting devices were certified for operations. The test article and the acoustic support structure in the reverberation chamber were installed in accordance with the test procedures document (Reference 2-2).

2.10.2 Test Article Preparation

The test article was certified to be ready for test operations by confirming the proper installation of the test article and support structure in the reverberation chamber in accordance with the test procedures document (Reference 2-2). No loose or damaged hardware items were encountered and all sensor mounting locations were accessible.

2.10.3 Test Equipment and Instrumentation Preparation

The correct configuration of the acoustic excitation sources and the position of the six control microphones around the test article in the reverberation chamber were verified. The layout of the reverberation chamber is depicted in Figure 2-11. The instrumentation arrangement was verified as specified in the test procedures document (Reference 2-2) and in the schematic of Figure 2-13. Photographs were taken of the pedestal mounted test article and the acoustic equipment in the reverberation chamber. The six control microphones were calibrated in accordance with the in-house calibration procedure as described in NASA Langley Management System document LMS-TD-0558. The calibration values are listed in Table 2-13.

Table 2-13: Control microphone calibrations.

Microphone Calibrations	[mV/Pa]	[mV/psi]
Microphone 1	11.14	76810.30
Microphone 2	10.67	73569.65
Microphone 3	11.49	79223.55
Microphone 4	11.74	80947.30
Microphone 5	10.88	75017.60
Microphone 6	12.18	83981.10

The calibration values were entered in the acoustic control system and the auxiliary DAS. An initial gain factor of 10 was applied to the accelerometer signals and low-pass filters were set to 20 kHz. A gain factor of 1000 was applied to the strain gages and low-pass filters were set to 10 kHz. It was verified that the correct control parameters were set up. The instrumented test article was visually inspected and found ready for testing. The valves in the reverberation chamber for the pressurized air to the pneumatic horn were opened in preparation for the acoustic excitation tests. The double doors of the reverberation chamber were closed. The pressurized air was switched on allowing flow to the reverberation room. The air pressure for the line to the #1 Ling driver was recorded at 33 psi and the line to the #2 Ling driver at 34 psi.

2.11 Dynamic Response Testing

All test runs were performed 27 May 2004.

Acoustic Run #1:
Start time: 13:27:20
Start level: -12 dB:
    Power spectra data stored in IDEAS file “acoustic_12_1.afu”
Start level: -9 dB:
    Power spectra data stored in IDEAS file “acoustic_9_1.afu”
Start level: -6 dB:

Power spectra data stored in IDEAS file “acoustic_6_1.afu”
General test parameters stored in file “test_ruddervator_a.rtf”
Control system log file stored in file “protocol_ruddervator_a.txt”
Microphone control system data stored in file “data_ruddervator_a.txt”
Stop time: 13:34:25 pm

The acoustic test run #1 was completed successfully. Drive signal and amplification were turned off for all sources. The air to the Ling drivers in the reverberation chamber was shut down and the doors were opened. The test article and instrumentation were visually inspected and approved for further testing. The doors were closed and the air to the chamber was re-opened. The microphone control data were checked to insure compliance with the measurement setup parameters in Table 2-9 and Table 2-10. Spectral plots of the control data channels were printed. Acoustic system setup and test parameters were attached.

Acoustic Run #2 (Attempt 1):
Start time: 13:47:55
Start level: -12 dB:
No IDEAS acquisition
Start level: -9 dB:
No IDEAS acquisition
Start level: -6 dB:
Power spectra data stored in IDEAS file “acoustic_6_2.afu”
Start level: -3 dB:
Power spectra data stored in IDEAS file “acoustic_3_2.afu”
Start level: 0 dB:
Power spectra data stored in IDEAS file “acoustic_0_2.afu”
Start level: -6 dB:
Power spectra data stored in IDEAS file “acoustic_6_2d.afu”
Start level: -12 dB:
No IDEAS acquisition
General test parameters stored in file “test_ruddervator_b.rtf”
Control system log file stored in file “protocol_ruddervator_b.txt”
Microphone control system data stored in file “data_ruddervator_b.txt”
Stop time: 14:07:59

The acoustic test run #2 was completed successfully, but was halted before power spectra data were acquired with the IDEAS data acquisition system. A restart of run #2 was performed to allow acquisition of the lacking IDEAS data.

Acoustic Run #2 (Attempt 2):
Start time: 14:08:31
Start level: -6 dB:
No IDEAS acquisition
Start level: -12 dB:
Power spectra data stored in IDEAS file “acoustic_12_2d.afu”
General test parameters stored in file “test_ruddervator_c.rtf”

Control system log file stored in file "protocol_ruddervator_c.txt"
Microphone control system data stored in file "data_ruddervator_c.txt"
Stop time: 14:12:17

The acoustic test run #2 (attempt 2) was completed successfully. Drive signal and amplification were turned off for all sources. The air to the Ling drivers in the reverberation chamber was shut down and the doors were opened. The test article and instrumentation were visually inspected and found to be in the same condition as before the acoustic testing had started. The microphone control data were checked to insure compliance with the measurement setup parameters in Table 2-9 and Table 2-10. Spectral plots of the control data channels were printed. Acoustic system setup and test parameters were attached.

The line air pressure to the #1 Ling driver was recorded as 33 psi before and after the acoustics tests. The line air pressure to the #2 Ling driver was recorded as 34 psi before and after the acoustics tests.

It was verified that the acoustics test of the C-C Ruddervator test article had successfully been completed.

2.12 Data Reporting

The VcpNT.ini file contains the initialization settings for the acoustic control system and is provided in text format. The general test parameters are included in a rich text format (.rtf) file. The acoustic control system protocol and data files are included in ASCII (American Standard Code for Information Interchange) format. The protocol files contain the time logs of all test related events. Starting time of each acoustic level change and times at which measurement data were taken are presented. The measurement data are in the control files and include the control, error, drive, and the six microphone spectra on a one-third octave band basis. All IDEAS test data for the accelerometers, strain gages, and microphones are available in electronic form in universal and spreadsheet formats. Data files were saved according to the channel numbers in Table 2-12. File names of the electronic data are listed in Table 2-14. Photographic documentation of the test is provided in JPEG format. All files were archived on compact disk.

Table 2-14: List of compact disk archived test, protocol, control, and IDEAS data files for all test runs.

Run #		Protocol File	Control File	Universal Data File	Spreadsheet Data File
1	test_ruddervator_a.rtf	VcpNT.ini protocol_ruddervator_a.txt	data_ruddervator_a.txt	acoustic_12_1.unv acoustic_9_1.unv acoustic_6_1.unv	acoustic_12_1.rpt acoustic_9_1.rpt acoustic_6_1.rpt
2/1	test_ruddervator_b.rtf	protocol_ruddervator_b.txt	data_ruddervator_b.txt	acoustic_6_2.unv acoustic_3_2.unv acoustic_0_2.unv acoustic_6_2d.unv	acoustic_6_2.rpt acoustic_3_2.rpt acoustic_0_2.rpt acoustic_6_2d.rpt
2/2	test_ruddervator_c.rtf	protocol_ruddervator_c.txt	data_ruddervator_c.txt	acoustic_12_2d.unv	acoustic_12_2d.rpt

2.13 References

2-1 Grosveld, Ferdinand W., "Calibration of the Structural Acoustic Loads and Transmission (SALT) Facility at NASA Langley Research Center," presented at the INTER-NOISE 99 International Congress on Noise Control Engineering, Fort Lauderdale, Florida, 6-8 December 1999.

2-2 Rice, Chad E., "X-37 Hot-Structures Control Surface, Carbon-Carbon Ruddervator Control Surface – Modal, Vibration, and Acoustics Test Procedures," NASA Langley Research Center, Hampton, Virginia, 13 May 2004.

3. C-C Flaperon

3.1 Introduction

Science Applications International Corporation (SAIC), under subcontract to The Boeing Company, is developing improved control surface structures for the Advanced Technology Vehicle (ATV) that will be flight-tested as part of the X-37 Orbital Vehicle Program. The Boeing X-37 vehicle incorporates a hot structure "Flaperon" control surface, made from oxidation-protected carbon-carbon (C-C), which will be subjected to vibratory and acoustic loads from the lift-off mission phase of flight. A subcomponent design for the C-C Flaperon was developed and manufactured. The goal of the hot structure Flaperon control surface vibro-acoustics tests is to simulate the dynamic response of the C-C Flaperon subcomponent when subjected to excitation loads corresponding to the lift-off environment, but at room temperatures. Measured responses will be compared to predicted strains and accelerations to determine the validity of the mathematical model for this C-C subcomponent test article. This report covers the vibro-acoustic testing in the reverberation chamber of the Structural Acoustics Loads and Transmission (SALT) facility (Reference 3-1) at NASA Langley Research Center.

3.2 Acoustic Test Objective

The objective of the acoustic test is to measure the dynamic response of the C-C Flaperon subcomponent when subjected to the acoustic loads corresponding to an envelope of the Atlas V and Delta IV launch environments. The measured responses (acceleration and strain) will be used to assess the construction techniques and mathematical model using a stochastic acoustic input that replicates the launch environment of the X-37 vehicle. This document describes the test article, the facility configuration, test setup, instrumentation, acoustic test loads spectra, test sequence, acoustic control and data acquisition systems, test results, and the data reporting of the C-C Flaperon subcomponent.

3.3 Test Article

The C-C Flaperon subcomponent test article consists of carbon-carbon composite materials fabricated by Carbon-Carbon Advanced Technologies, Inc. The subcomponent test article (STA) is a truncated full-scale replica of the flight hardware that incorporates all major structural components, such as the torque tube, spindle, hinge pin, and ribs. The test article is a full scale part starting at the inboard edge of the component and including the actual spindle and torque tube diameters. The overall dimensions of the test article are 37 in. long by 18.7 in. wide by 5 in. thick. The C-C Flaperon test article with the access panel removed is shown in Figure 3-1.

Figure 3-1: C-C Flaperon test article with access panel removed.

The test article was mounted on an aluminum interface plate as shown in the sketch of Figure 3-2. A support structure (Figure 3-3) was bolted to the floor of the reverberation chamber and filled with sand. The support structure was used to elevate the test article for better exposure to the acoustic excitation loads. The test article and aluminum interface plate were mounted to the top of the support structure. The test procedures document in Reference 3-2 provides the details on the designs, the drawings, and test setup installation procedures of the test article and support structure.

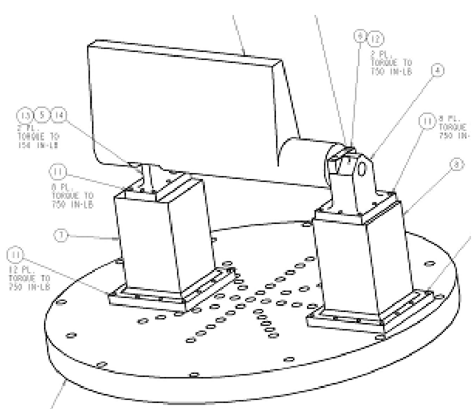

Figure 3-2: Test article and aluminum interface plate.

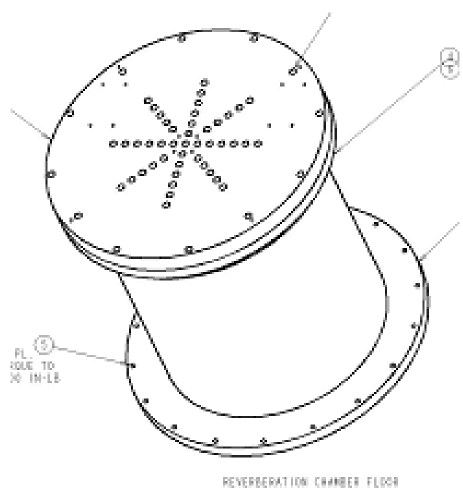

Figure 3-3: Test article support structure.

3.4 Test Article Instrumentation

The instrumentation sensor suite consisted of fifteen accelerometers and twelve strain gage sensors (four rosettes). Figure 3-4 shows the fifteen accelerometer locations in five tri-axial configurations. Small 0.02 oz, 10 mV/g, PCB 352C22 accelerometers were used for these tests. The tri-axial configurations were achieved using an accelerometer mounting block. The weight of the mounting block was typically 0.08 oz. The X, Y, and Z coordinate axes for the accelerometers are shown in Figure 3-5.

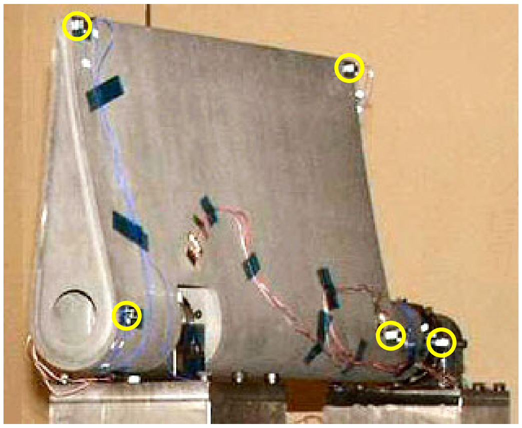

Figure 3-4: Locations of the five tri-axial accelerometers.

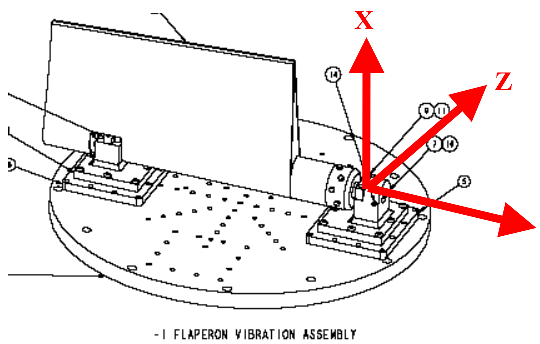

Figure 3-5: Coordinate axes for the accelerometers.

Table 3-1 lists the accelerometer model, serial numbers, sensitivities, and orientations.

Table 3-1: Accelerometer model, serial numbers, sensitivities, and orientations.

Accelerometer	Model	Serial Number	Sensitivity [mV/g]	Orientation
A3	352C22	18405	9.557	A1X
A4	352C22	18408	9.860	A1Y
A5	352C22	18410	10.17	A1Z
A6	352C22	18411	9.610	A2X
A7	352C22	18412	10.42	A2Y
A8	352C22	18413	9.977	A2Z
A9	352C22	18415	9.960	A3X
A10	352C22	18416	9.885	A3Y
A11	352C22	18418	9.812	A3Z
A12	352C22	18419	9.760	A4X
A13	352B22	11711	9.539	A4Y
A14	352C22	18421	10.07	A4Z
A15	352C22	18399	9.912	A5X
A16	352B22	11714	9.551	A5Y
A17	352B22	11710	9.885	A5Z

The locations of the four foil strain gage rosettes are shown in Figure 3-6. The instrumented test article is shown in Figure 3-4. Exact locations and orientations of the strain gages are provided in Reference 3-2.

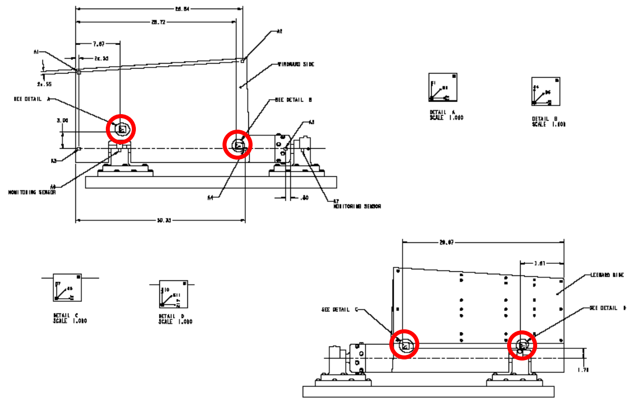

Figure 3-6: Locations of the four foil strain gage rosettes.

3.5 Acoustic Test Facility

The 9800 ft^3 SALT facility reverberation chamber (Reference 3-1) measures approximately 14.8 ft by 21.2 ft by 31.2 ft and is structurally isolated from the rest of the building. Figure 3-7 shows the reverberation chamber with the instrumented test article mounted on the sand-filled pedestal support. Rigid close-out panels (not shown in the picture) were installed in the transmission loss window (separating the reverberation chamber from the anechoic chamber) and the flow duct protrusion.

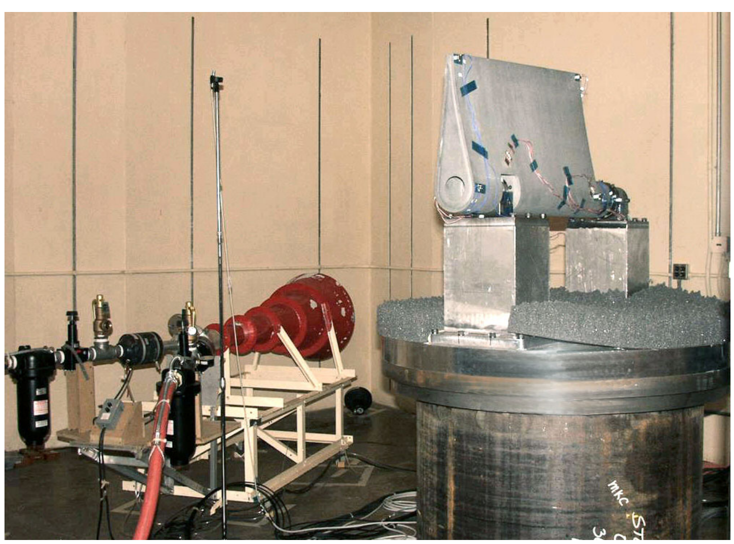

Figure 3-7: Test article mounted on the pedestal support structure in the reverberation chamber.

The chamber walls and ceiling of the reverberation chamber are splayed to diminish the effects of standing waves between opposite surfaces and are separated by a 30-inch air gap from the surrounding 18-inch thick concrete building walls. The total surface area of the walls, floor, and ceiling is approximately 3120 ft^2. One-third octave band ambient noise levels were measured previously (Reference 3-1) in the reverberation chamber and are listed in Table 3-2. The minimum frequency for a diffuse sound field in the reverberation chamber was calculated to be 83.2 Hz yielding the one-third octave bands with 100 Hz and higher center frequencies exhibiting diffuse sound conditions (Reference 3-1). Table 3-2 also lists the T(20) reverberation times, the estimated times required for the sound pressure level (SPL) to decrease 60 dB, extrapolated from the SPL decays between –5 dB and –25 dB.

Table 3-2: Background noise levels and reverberation times in the reverberation room.

One-Third Octave Band Center Frequency [Hz]	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000
Background Noise Level [dB]	34.4	32.1	43.2	27.6	26.9	28.9	22.6	20.7	12.4	12.6	12.3	10.2	9.5	7.6	7
Reverberation Time (T20) [s]	23.3	15.0	13.5	14.2	15.8	15.3	14.9	13.7	12.4	10.8	9.4	8.4	7.0	5.8	5.1

3.6 Test Equipment and Instrumentation

Excitation in the reverberation chamber was provided by three types of acoustic drivers to cover the one-third octave band frequency range from 40 Hz through 2000 Hz. The low frequencies were generated by two subwoofers, the mid-frequencies by a dual-driver pneumatic horn, and the high frequencies were generated by compact compression drivers. Figure 3-8 shows one of the subwoofers and one of the compression drivers in the reverberation chamber.

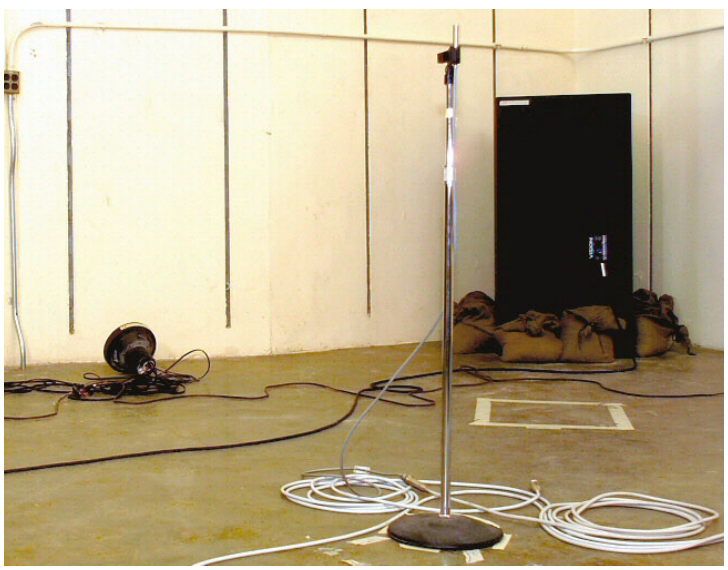

Figure 3-8: The low-frequency subwoofer (right) and high-frequency compression driver (left on the floor).

The pneumatic horn in the reverberation chamber is depicted in Figure 3-9. An acoustic control system used the averaged measured signals of six control microphones to generate the required acoustic spectrum shape inside the reverberation chamber by independently adjusting the input signal to each of the three types of acoustic drivers. The control system will be described in detail in Section 3.8. Descriptions of the acoustic equipment, instrumentation, and settings used during the tests, including model, serial number, and calibration information are listed in Table 3-3 and Table 3-4. Other support equipment and instrumentation for installation of the test article and acquisition of the acceleration and strain data are summarized in Table 3-5.

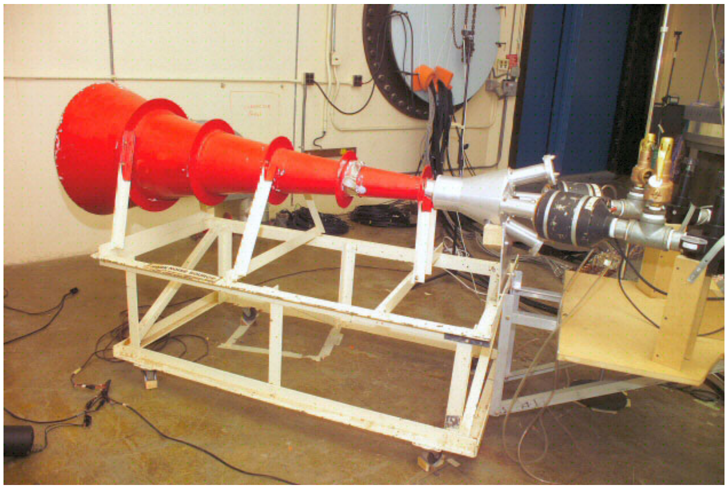

Figure 3-9: The pneumatic horn outfitted with two mid-frequency acoustic drivers.

Table 3-3: Acoustic equipment and instrumentation descriptions for the X-37 C-C Flaperon testing.

A1 **Amplifier** Crown Micro-Tech 600 A019775 Bridge Mono 655 Watts at 8 Ohms Input: XLR 1 Output: +1, +2 Gain: Full	**A2** **Amplifier** Crown Micro-Tech 600 A019774 Bridge Mono 655 Watts at 8 Ohms Input: XLR 1 Output: +1, +2 Gain: Full	**A3 and A4** **Amplifier** Crown CE4000 Bridge Mono 2800 Watts at 4 Ohms Input: XLR 1 Output: +1, +2 Sensitivity: 1.4 V Ch1: Flat low-pass Ch2: N/A Gain: Full
A5 **Amplifier** Crown Micro-Tech 600 A019773 Bridge Mono 655 Watts at 8 Ohms Input: XLR 1 Output: +1, +2 Gain: Full	**A6** **Amplifier** Crown Micro-Tech 600 A019773 Bridge Mono 655 Watts at 8 Ohms Input: XLR 1 Output: +1, +2 Gain: Full	**F1** **Filter** Krohn-Hite 3342R A033067 ECN 429787 Freq 1 Hz High Pass Line Opr Gain: 20 dB Left channel 1 (Front) Right channel not used
Sc1 **8-Channel Multiplexer** Bruel & Kjaer Model 2811 Use: Signal Conditioning Ser: 1607595 ECN: 1090893 Cal due: 5/17/05	**Ec1** **Acoustic Control System** M+P International, Inc. VXI Technology VT1433B input	**Pph1** **Sound Level Calibrator** General Radio 1562-A Nominal: 114.0 dB at 500 Hz Ser: 7960 ECN: A025926 Cal due: 11/10/04
L1 and L2 (mid) **Pneumatic Horn** Ling (2) Model: EPT94B Frequency Range: 100Hz-1000Hz	**L3 and L4 (low)** **Dual 18" Subwoofer** Cerwin Vega (2) Vis-218 Parallel Mode Input Frequency Range: 29Hz-300Hz Peak: 2800 Watts	**L5 - L10 (high)** **Compression Driver** JBL (6) Model: 2485J Frequency Range: 300Hz-6kHz Continuous: 120 Watts

Table 3-4: Microphone and preamplifier specifications.

Mic1 **Microphone** Bruel & Kjaer 4133 Ser: 488997 MCN: A037057 Cal: 05/14/05	**Mic2** **Microphone** Bruel & Kjaer 4133 Ser: 489484 MCN: A037050 Cal: 05/14/05	**Mic3** **Microphone** Bruel & Kjaer 4134 Ser: 173455 MCN: A037055 Cal: 05/14/05	**Mic4** **Microphone** Bruel & Kjaer 4133 Ser: 1854447 MCN: A019642 Cal: 05/14/05	**Mic5** **Microphone** Bruel & Kjaer 4133 Ser: 1854444 MCN: A037051 Cal: 05/14/05	**Mic6** **Microphone** Bruel & Kjaer 4133 Ser: 1854446 MCN: A037053 Cal: 05/14/05
Mp1 **Microphone** **Preamplifier** Bruel & Kjaer 2619 Ser: 761358 MCN: A004353 Cal: 05/13/05	**Mp2** **Microphone** **Preamplifier** Bruel & Kjaer 2619 Ser: 1649717 MCN: A004357 Cal: 05/13/05	**Mp3** **Microphone** **Preamplifier** Bruel & Kjaer 2619 Ser: 692811 MCN: A004354 Cal: 05/13/05	**Mp4** **Microphone** **Preamplifier** Bruel & Kjaer 2619 Ser: 360362 MCN: A004284 Cal: 05/13/05	**Mp5** **Microphone** **Preamplifier** Bruel & Kjaer 2619 Ser: 797667 MCN: A004280 Cal: 05/13/05	**Mp6** **Microphone** **Preamplifier** Bruel & Kjaer 2619 Ser: 521525 MCN: A002640 Cal: 05/13/05

Table 3-5: Test article support equipment and instrumentation.

Description	Quantity	Manufacturer	Model / Part Number
Test article structural support:			
Aluminum Interface Plate	1	AmTech	Drawing # 1256396
Steel Adaptor Plate	1	AmTech	Drawing # 1256402
Support Structure	1	AmTech	Drawing # 1256401
Vibration sensors:			
Measurement Accelerometers	15	PCB	352C22/352B22
Foil Strain Gages (Four Rosettes)	12	Micro-Measurements	CEA-06-250UR-350
Signal conditioning system:			
Chassis/Power supply	1	PCB	441A01
16-Channel Signal Conditioning	4	PCB	442A126
Bridge Signal Conditioning	12	Pacific	5500
Control system DAS:			
HP PC Computer	1	HP	2100795
HP VXI System Mainframe	1	HP	E8408A
HP VXI Interface	1	HP	E8491B
HP 8-Channel Digitizer + DSP	1	HP	VT1433B
M+P International Acoustic Control Software	1	M+P	Version 2.7.2
Auxiliary DAS:			
MTS Master Series Software (IDEAS)	1	MTS	Version 7
PC computer	1	HP	TAFA-ACQ
HP VXI System Mainframe	1	HP	E8403A
HP VXI Interface	1	HP	E8491B
HP 16-Channel Digitizer	3	HP	1432A

The layout of the reverberation chamber for acoustic testing of the Flaperon subcomponent test article is illustrated in Figure 3-10. The locations of the low-frequency (L3 and L4), the mid-frequency (L1 and L2), and the high-frequency (L5-L10) acoustic drivers are shown in Figure 3-10. The locations of the control microphones (Mic1-Mic6) around the test article support structure in the center of the chamber are also depicted. The height of each microphone is indicated next to its identification, e.g., the height of Microphone 1 is 77 inches off the floor.

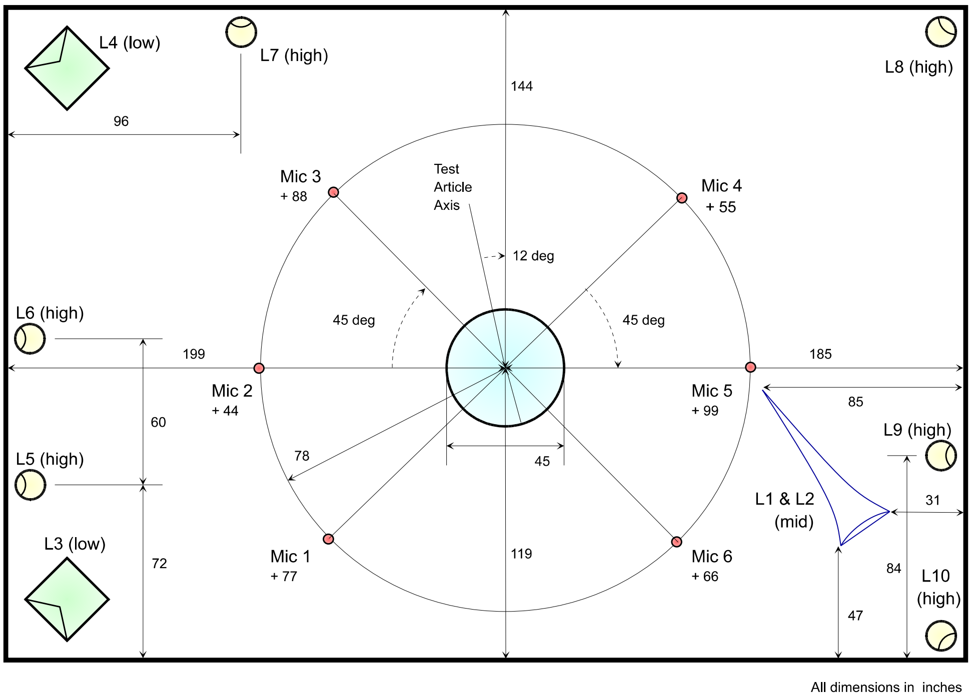

Figure 3-10: Acoustic drivers and control microphones in the reverberation room.

3.7 Dynamic Response Test Description

The Flaperon was exposed to one-third octave band acoustic excitation derived from a bounding of Atlas V and Delta IV launch environments acoustic spectra. The acoustic spectrum shape and level was produced using a one-third octave band control system. Data acquisition included acoustic levels from the six control microphones in the reverberation chamber and accelerometers and strain gages (measurement response) mounted on the test article.

3.7.1 Acoustic Test Level

The one-third octave band acoustic excitation spectra for the Atlas V, Delta IV, and the X-37 are shown in Table 3-6. The X-37 enveloped spectrum represents an overall sound pressure level (OASPL) of 140.8 dB. The acoustic test spectrum is graphically depicted in Figure 3-11. The one-third octave band with a center frequency of 31.5 Hz was not controlled by the acoustic control system in the reverberation chamber test. The OASPL of the controlled spectrum was 140.67 dB with the 31.5 Hz one-third octave band not participating. The acoustic excitation spectrum generated and controlled in the reverberation chamber is shown in the last column of Table 3-6.

Table 3-6: X-37 one-third-octave band acoustic excitation spectra.

One-Third Octave Band Center Frequency [Hz]	Atlas V (5m Composite Faring, 95/50, 50% fill) [dB]	Delta IV M+ (5m Composite Faring, 95/50, 60% fill) [dB]	Bounded X-37 Spectrum [dB]	Reverberation Chamber Acoustic Test [dB]
31.5	124.5	123	124.5	
40	127	126	127	127
50	128.3	128	128.3	128.3
63	129.5	129.5	129.5	129.5
80	130	130.5	130.5	130.5
100	130.5	130.5	130.5	130.5
125	130.5	130.5	130.5	130.5
160	130.2	130.5	130.5	130.5
200	129.5	130.5	130.5	130.5
250	129	130.5	130.5	130.5
315	128	130	130	130
400	126.5	128	128	128
500	125.5	126	126	126
630	124.5	123	124.5	124.5
800	123	121	123	123
1000	121.5	119	121.5	121.5
1250	120	117.5	120	120
1600	118	116	118	118
2000	116	115	116	116
OASPL=	**140.3**	**140.6**	**140.8**	**140.67**

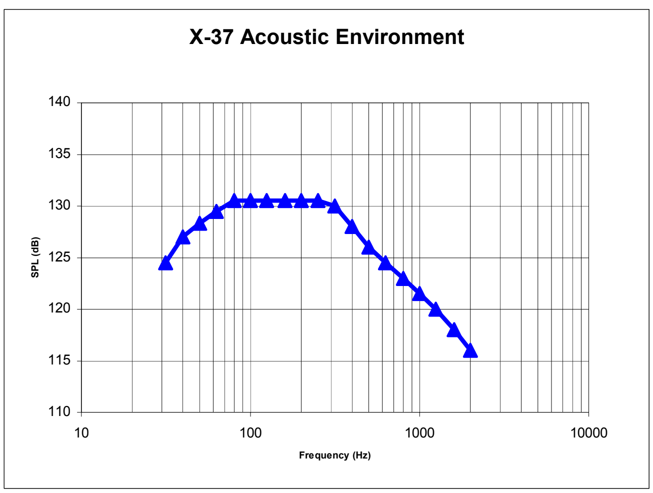

Figure 3-11: Graphical representation of the X-37 one-third octave band acoustic excitation spectrum.

3.7.2 Acoustic Excitation Test Schedule

The test procedures document (Reference 3-2) stipulates an acoustic excitation applied according to the test schedule listed in Table 3-7. The shape of the acoustic spectrum, specified in the last column of Table 3-6, was identical for all overall sound pressure levels. Excitation and response data were acquired at each level and the data were reviewed to ascertain data integrity. The test article was visually inspected after runs #1 and #2.

Table 3-7: X-37 acoustic test schedule in the reverberation room.

Acoustic Run #1			Acoustic Run #2		
OASPL [dB]	**Delta dB [dB]**	**Data Acquisition (Y/N)**	**OASPL [dB]**	**Delta dB [dB]**	**Data Acquisition (Y/N)**
128.67	-12	Y	128.67	-12	N
131.67	-9	Y	131.67	-9	N
134.67	-6	Y	134.67	-6	Y
			137.67	-3	Y
			140.67	0	Y
			134.67	-6	Y
			128.67	-12	Y

3.8 Acoustic Control System

The acoustic control system consisted of a personal computer, running one-third octave band control software from M+P, and a VXI-based front-end (Figure 3-12). The control system output was routed to a DP224 three-way crossover filter to split the output signal into low-, middle-, and high-frequency ranges. Following amplification, these were directed to acoustic drivers, the combined output of which was measured by the six control microphones. A frequency control region was programmed for each of the acoustic driver types by setting high-pass and low-pass frequencies along with filter and slope specifications. The three-way crossover settings for all tests are listed in Table 3-8.

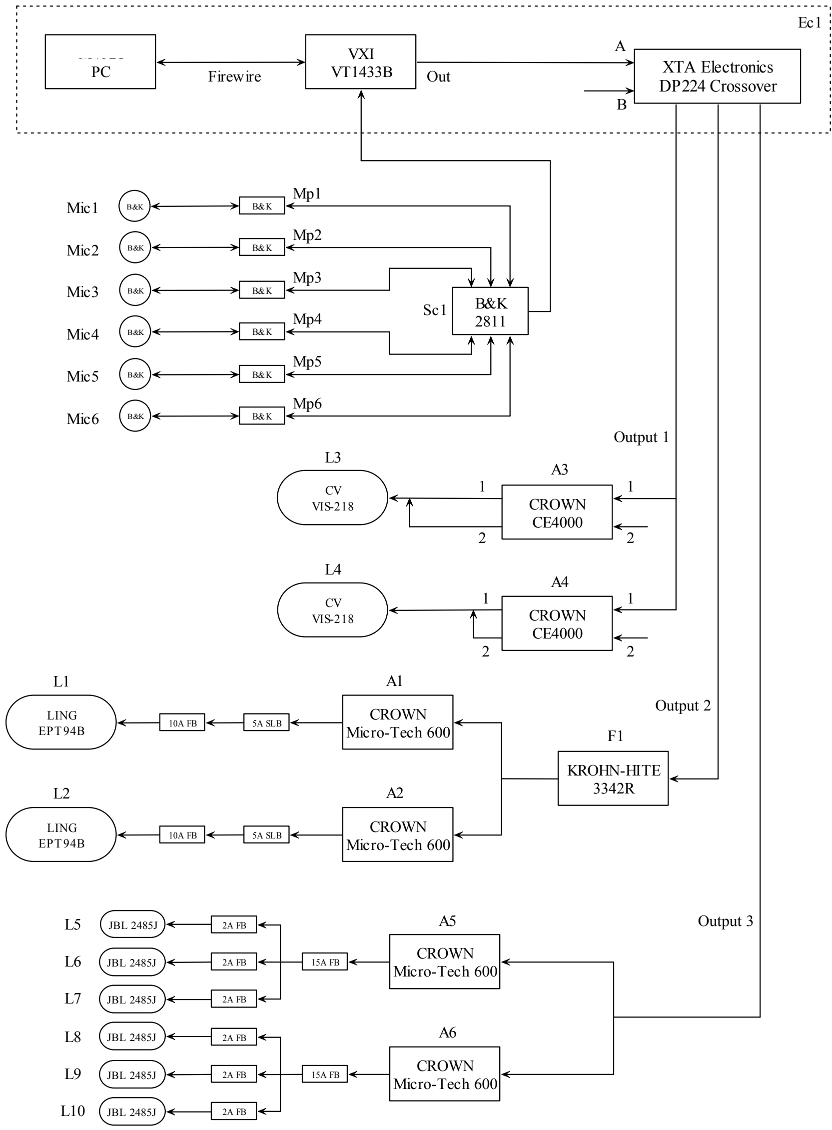

Figure 3-12: Schematic of acoustic control system configuration.

Table 3-8: DP224 three-way crossover settings.

Acoustic Driver	High-Pass Frequency [Hz]	Filter	Slope [dB/octave]	Low-Pass Frequency [Hz]	Filter	Slope [dB/octave]
Subwoofer	13.9	Link/Riley	24	120	Butterworth	18
Pneumatic horn	80.3	Butterworth	18	2000	Link/Riley	24
Compression driver	794	Butterworth	24	5040	Butterworth	24

A graphical representation of the different control regions is shown in Figure 3-13.

Figure 3-13: The control regions for low-, mid-, and high-frequency acoustic drivers.

Measurement set-up parameters for the acoustic control system are tabulated in Table 3-9.

Table 3-9: Measurement setup parameters.

Measurement Parameter	Acoustic Test
Minimum one-third octave band analysis bandwidth	40 – 2000 Hz
Minimum spectral resolution	One-third octave
Overall sound pressure level (OASPL)	+3 dB, -1 dB
Control tolerance (40 Hz one-third octave band)	+3 dB, -3 dB
Control tolerance (50-2000 Hz one-third octave band)	+4 dB, -2 dB

Table 3-10 shows the reverberation chamber acoustic test sound pressure levels (listed in the last column of Table 3-6) along with the limits set for the acoustic control system.

Table 3-10: Sound pressure levels and limits set in acoustic control system.

One-Third Octave Band Center Frequency [Hz]	Sound Pressure Level [dB]	Low Alarm [dB]	High Alarm [dB]	Abort [dB]
40	127	-3	3	6
50	128.3	-2	4	6
63	129.5	-2	4	6
80	130.5	-2	4	6
100	130.5	-2	4	6
125	130.5	-2	4	6
160	130.5	-2	4	6
200	130.5	-2	4	6
250	130.5	-2	4	6
315	130	-2	4	6
400	128	-2	4	6
500	126	-2	4	6
630	124.5	-2	4	6
800	123	-2	4	6
1000	121.5	-2	4	6
1250	120	-2	4	6
1600	118	-2	4	6
2000	116	-2	4	6
OASPL	140.67	-1	1	3

The advanced control system parameters in Table 3-11 were set to abort the test when those criteria were exceeded.

Table 3-11: Advanced measurement setup parameters.

Advanced Control Parameters		
Time constant	1.0	[s]
Maximum number of octave bands tolerated in abort	5	
Maximum time octave bands can be in abort	5.0	[s]
Maximum time overall sound pressure level (OASPL) can be in abort	10.0	[s]
Maximum microphones can deviate from average	6.0	[dB]
Maximum time microphones can deviate	10.0	[s]
Minimum number of valid microphones	3	

3.9 Data Acquisition System

The auxiliary data acquisition and acoustic control systems are shown in Figure 3-14. The auxiliary data acquisition system (DAS) consisted of a personal computer running MTS IDEAS and a VXI-based front-end. The DAS was used to acquire response data from accelerometers and strain gages mounted on the test article. In addition, the DAS recorded the acoustic excitation measured by the control microphones. The transducer channels operated for the DAS are referenced in Table 3-12. Channel 28 was not used. The DAS was set up to acquire power spectral density (PSD) data for each channel. All data acquired via the DAS system were stored in engineering units in the English system of units. Calibration and amplification information provided throughout this report are therefore for reference only. They do not need to be applied to the data. Acceleration PSD data are provided in units of $(in/s^2)^2/Hz$. Strain PSD data are provided in units of $(in/in)^2/Hz$. Microphone PSD data are provided in units of $(lbf/in^2)^2/Hz$.

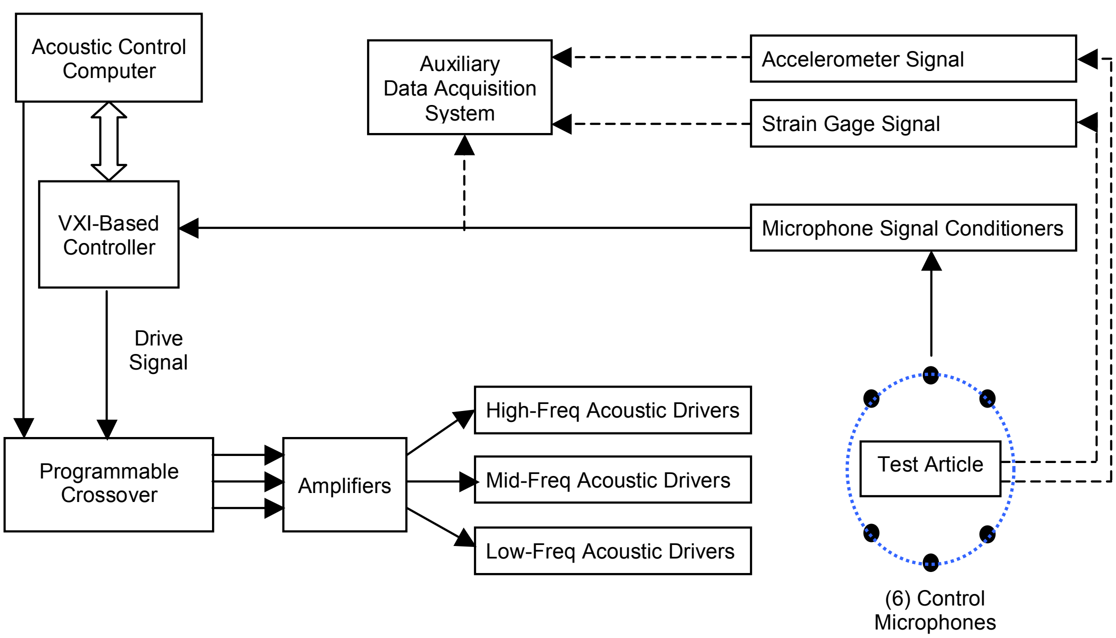

Figure 3-14: Auxiliary data acquisition and acoustic control system configuration.

Table 3-12: IDEAS channel identification numbers, associated transducers, and their serial (MCN) numbers.

Channel	Transducer	#	Serial #	Channel	Transducer	#	Serial #	Channel	Transducer	#	Serial #
1	Foil strain gage	S1	N/A	13	Accelerometer	A3	18405	25	Accelerometer	A15	18399
2	Foil strain gage	S2	N/A	14	Accelerometer	A4	18408	26	Accelerometer	A16	11714
3	Foil strain gage	S3	N/A	15	Accelerometer	A5	18410	27	Accelerometer	A17	11710
4	Foil strain gage	S4	N/A	16	Accelerometer	A6	18411	28	Empty		
5	Foil strain gage	S5	N/A	17	Accelerometer	A7	18412	29	Microphone	M1	488997
6	Foil strain gage	S6	N/A	18	Accelerometer	A8	18413	30	Microphone	M2	489484
7	Foil strain gage	S7	N/A	19	Accelerometer	A9	18415	31	Microphone	M3	173455
8	Foil strain gage	S8	N/A	20	Accelerometer	A10	18416	32	Microphone	M4	1854447
9	Foil strain gage	S9	N/A	21	Accelerometer	A11	18418	33	Microphone	M5	1854444
10	Foil strain gage	S10	N/A	22	Accelerometer	A12	18419	34	Microphone	M6	1854446
11	Foil strain gage	S11	N/A	23	Accelerometer	A13	11711				
12	Foil strain gage	S12	N/A	24	Accelerometer	A14	18421				

3.10 Test Preparation Procedures

3.10.1 Facility Preparation

The reverberation chamber of the SALT facility was prepared for the acoustic testing and declared ready for operations. All appropriate instrumentation was verified to be available, in calibration if required and in working condition. Facility-lifting devices were certified for operations. The test article and the acoustic support structure in the reverberation chamber were installed in accordance with the test procedures document (Reference 3-2).

3.10.2 Test Article Preparation

The test article was certified to be ready for test operations by confirming the proper installation of the test article and support structure in the reverberation chamber in accordance with the test procedures document (Reference 3-2). No loose or damaged hardware items were encountered and all sensor mounting locations were accessible.

3.10.3 Test Equipment and Instrumentation Preparation

The correct configuration of the acoustic excitation sources and the position of the six control microphones around the test article in the reverberation chamber were verified. The layout of the reverberation chamber is depicted in Figure 3-10. The instrumentation arrangement was verified as specified in the test procedures document (Reference 3-2) and in the schematic of Figure 3-12. Photographs were taken of the pedestal mounted test article and the acoustic equipment in the reverberation chamber. The six control microphones were calibrated in accordance with the in-house calibration procedure as described in NASA Langley Management System document LMS-TD-0558. The calibration values are listed in Table 3-13.

Table 3-13: Control microphone calibrations.

Microphone Calibrations	[mV/Pa]	[mV/psi]
Microphone 1	11.40	78600.23
Microphone 2	10.99	75773.38
Microphone 3	11.67	80461.82
Microphone 4	11.84	81633.93
Microphone 5	11.24	77497.07
Microphone 6	12.22	84253.93

The calibration values were entered in the acoustic control system and the auxiliary DAS. An initial gain factor of 10 was applied to the accelerometer signals and low-pass filters were set to 20 kHz. A gain factor of 1000 was applied to the strain gages and low-pass filters were set to 10 kHz. It was verified that the correct control parameters were set up. The instrumented test article was visually inspected and found ready for testing. The valves in the reverberation chamber for the pressurized air to the pneumatic horn were opened in preparation for the acoustic excitation tests. The double doors of the reverberation chamber were closed. The pressurized air was switched on allowing flow to the reverberation room. The air pressures for the lines to the #1 and the #2 Ling drivers were both recorded at 34 psi.

3.11 Dynamic Response Testing

All test runs were performed 30 June 2004.

Acoustic Run #1:
Start time: 15:18:10
Start level: -12 dB:
    Power spectra data stored in IDEAS file "acoustic_12_1.afu"
Start level: -9 dB:
    Power spectra data stored in IDEAS file "acoustic_9_1.afu"
Start level: -6 dB:
    Power spectra data stored in IDEAS file "acoustic_6_1.afu"
General test parameters stored in file "test_CC_FLAP _a.rtf"
Control system log file stored in file "protocol_CC_FLAP_a.txt"
Microphone control system data stored in file "data_CC_FLAP_a.txt"
Stop time: 15:23:38

The acoustic test run #1 was completed successfully. Subsequently, drive signal and amplification were turned off for all sources. The air to the Ling drivers in the reverberation chamber was shut down and the doors were opened. The test article and instrumentation were visually inspected and approved for further testing. The doors were closed and the air to the chamber was re-opened. The microphone control data were checked to insure compliance with the measurement setup parameters in Table 3-9, Table 3-10, and Table 3-11. Spectral plots of the control data channels were printed. Acoustic system setup and test parameters were attached.

Acoustic Run #2 (Attempt 1):
Start time: 15:38:02
Start level: -12 dB:
    No IDEAS acquisition

Start level: -9 dB:
    No IDEAS acquisition
Start level: -6 dB:
    Power spectra data stored in IDEAS file "acoustic_6_2.afu"
Start level: -3 dB:
    Power spectra data stored in IDEAS file "acoustic_3_2.afu"
General test parameters stored in file "test_CC_FLAP_b.rtf"
Control system log file stored in file "protocol_CC_FLAP_b.txt"
Microphone control system data stored in file "data_CC_FLAP_b.txt"
Stop time: 15:44:58

The acoustic test run #2 was halted as a faulty cable caused signal loss to the mid-frequency pneumatic horn drivers. The control system was unable to produce the required X-37 spectrum shape and levels without the full contribution of the pneumatic horn generated noise. The problem was remedied by replacing the defective cable. A restart of run #2 was performed.

Acoustic Run #2 (Attempt 2):
Start time: 16:17:38
Start level: -12 dB:
    No IDEAS acquisition
Start level: -9 dB:
    No IDEAS acquisition
Start level: -6 dB:
    No IDEAS acquisition
Start level: -3 dB:
    No IDEAS acquisition
Start level: 0 dB:
    Power spectra data stored in IDEAS file "acoustic_0_2.afu"
Start level: -6 dB:
    Power spectra data stored in IDEAS file "acoustic_6_2d.afu"
Start level: -12 dB:
    Power spectra data stored in IDEAS file "acoustic_12_2d.afu"
General test parameters stored in file "test_CC_FLAP_b.rtf"
Control system log file stored in file "protocol_CC_FLAP_c.txt"
Microphone control system data stored in file "data_CC_FLAP_c.txt"
Stop time: 16:25:54

The acoustic test run #2 was completed successfully. Drive signal and amplification were turned off for all sources. The air to the Ling drivers in the reverberation chamber was shut down and the doors were opened. The test article and instrumentation were visually inspected and found to be in the same condition as before the acoustic testing had started. The microphone control data were checked to insure compliance with the measurement setup parameters in Table 3-9, Table 3-10, and Table 3-11. Spectral plots of the control data channels were printed. Acoustic system setup and test parameters were attached. The line air pressures to both the #1 Ling and the #2 Ling drivers were recorded as 34 psi before and after the acoustics tests. It was verified that the acoustics test of the C-C Flaperon test article had successfully been completed.

3.12 Data Reporting

The VcpNT.ini file contains the initialization settings for the acoustic control system and is provided in text format. The general test parameters are presented in a rich text format (.rtf) file. The acoustic control system protocol and data files are included in ASCII (American Standard Code for Information Interchange) format. The protocol files contain the time logs of all test related events. Starting time of each acoustic level change and times at which measurement data were taken are presented. The measurement data are in the control files and include the control, error, drive, and the six microphone spectra on a one-third octave band basis. All IDEAS test data for the accelerometers, strain gages, and microphones are available in electronic form in universal and spreadsheet formats. Data files were saved according to the channel numbers in Table 3-12. File names of the electronic data are listed in Table 3-14. Photographic documentation of the test is provided in JPEG format. All files were archived on compact disk.

Table 3-14: List of compact disk archived test, protocol, control, and IDEAS data files for all test runs.

Run #	Test Parameters	Protocol File	Control File	Universal Data File	Spreadsheet Data File
1	test_CC_FLAP_a.rtf	VcpNT.ini protocol_CC_FLAP_a.txt	data_CC_FLAP_a.txt	acoustic_12_1.unv acoustic_9_1.unv acoustic_6_1.unv	acoustic_12_1.rpt acoustic_9_1.rpt acoustic_6_1.rpt
2/1	test_CC_FLAP_b.rtf	protocol_CC_FLAP_b.txt	data_CC_FLAP_b.txt	acoustic_6_2.unv acoustic_3_2.unv	acoustic_6_2.rpt acoustic_3_2.rpt
2/2	test_CC_FLAP_b.rtf	protocol_CC_FLAP_c.txt	data_CC_FLAP_c.txt	acoustic_0_2.unv acoustic_6_2d.unv acoustic_12_2d.unv	acoustic_0_2.rpt acoustic_6_2d.rpt acoustic_12_2d.rpt

3.13 References

3-1 Grosveld, Ferdinand W., “Calibration of the Structural Acoustic Loads and Transmission (SALT) Facility at NASA Langley Research Center,” presented at the INTER-NOISE 99 International Congress on Noise Control Engineering, Fort Lauderdale, Florida, 6-8 December 1999.

3-2 Rice, Chad E., “X-37 Hot-Structures Control Surface, Carbon-Carbon Ruddervator Control Surface – Modal, Vibration, and Acoustics Test Procedures,” NASA Langley Research Center, Hampton, Virginia, 13 May 2004.

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